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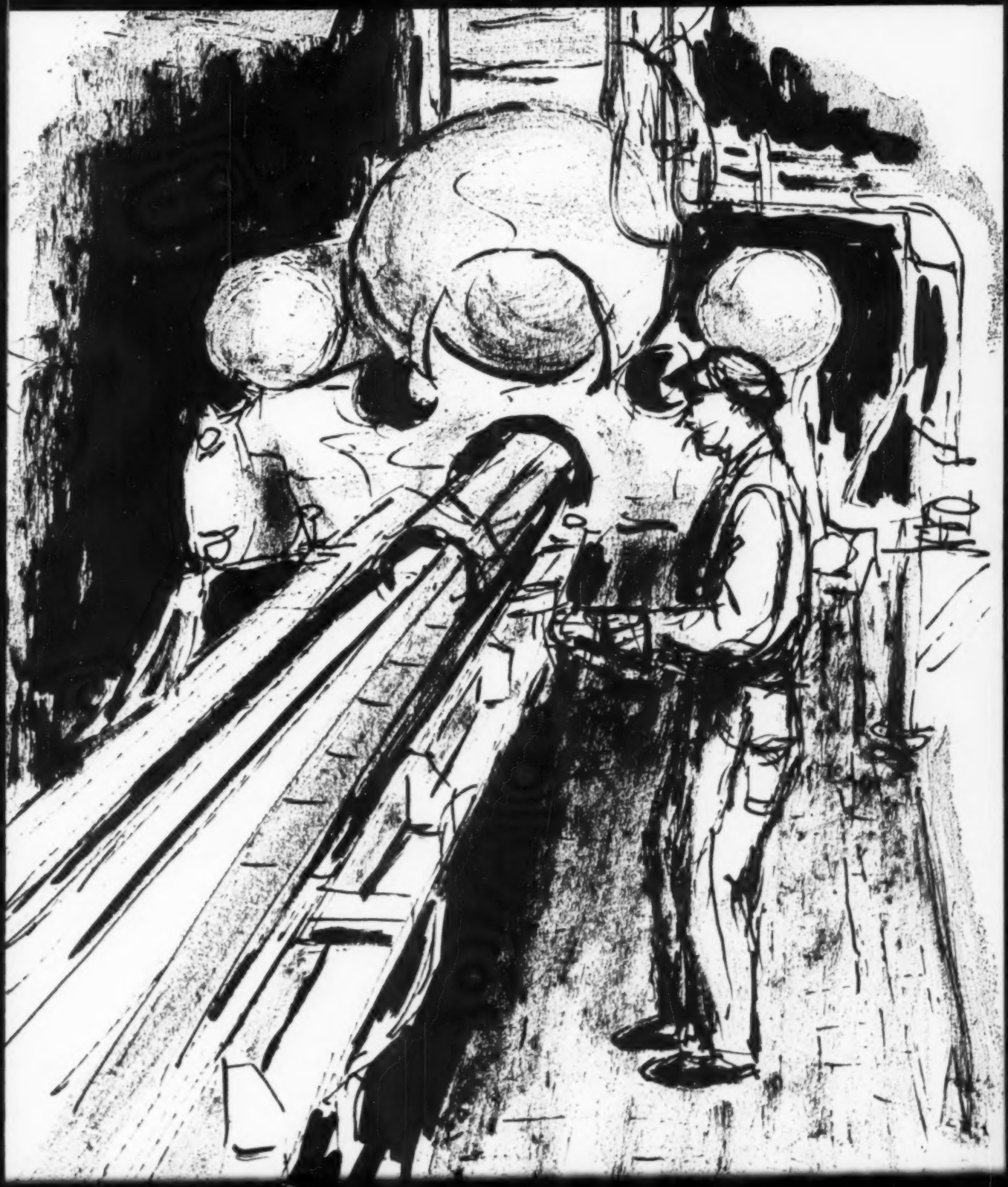
METALS

MARCH 1961



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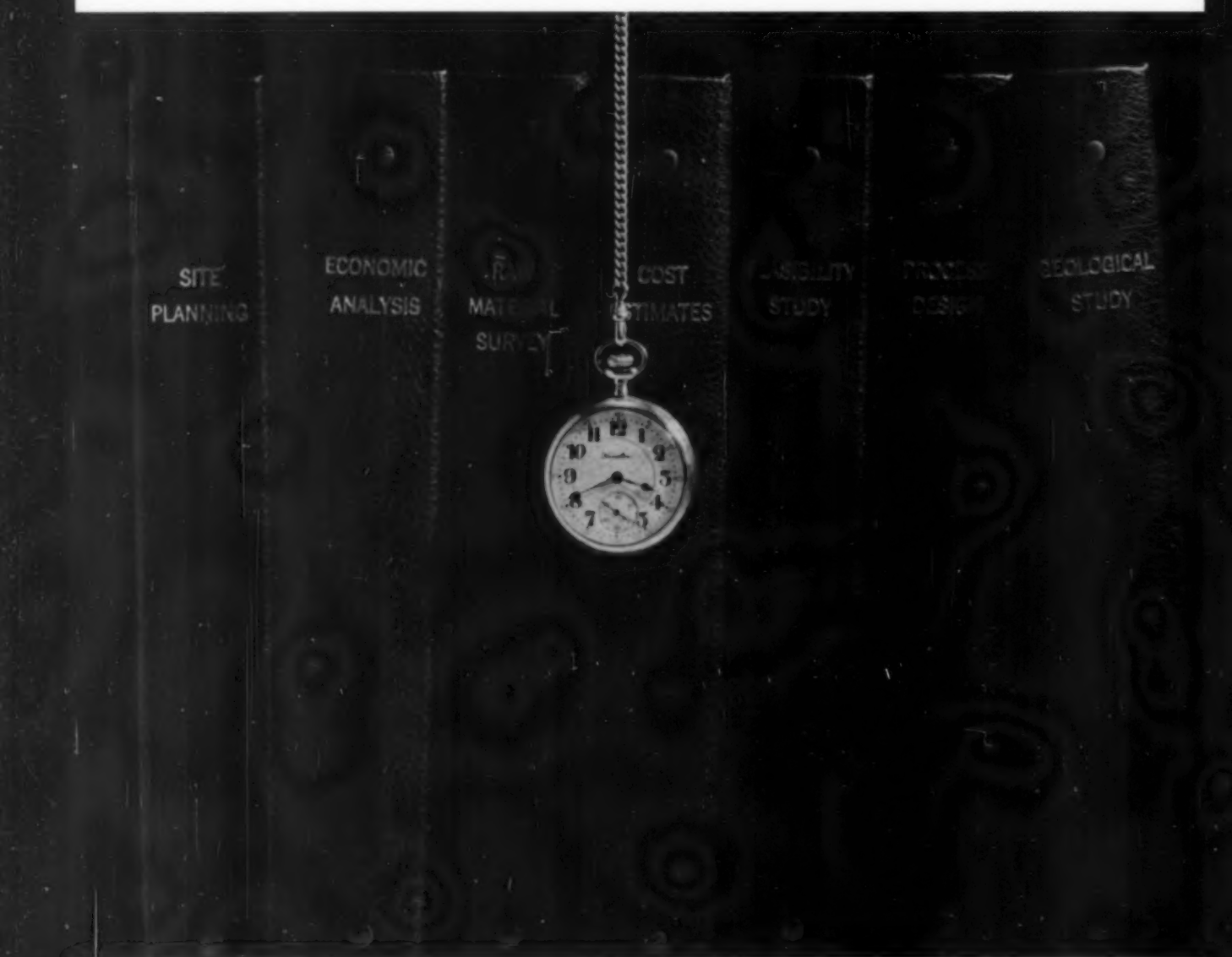

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Vol. 13, No. 3
March, 1961

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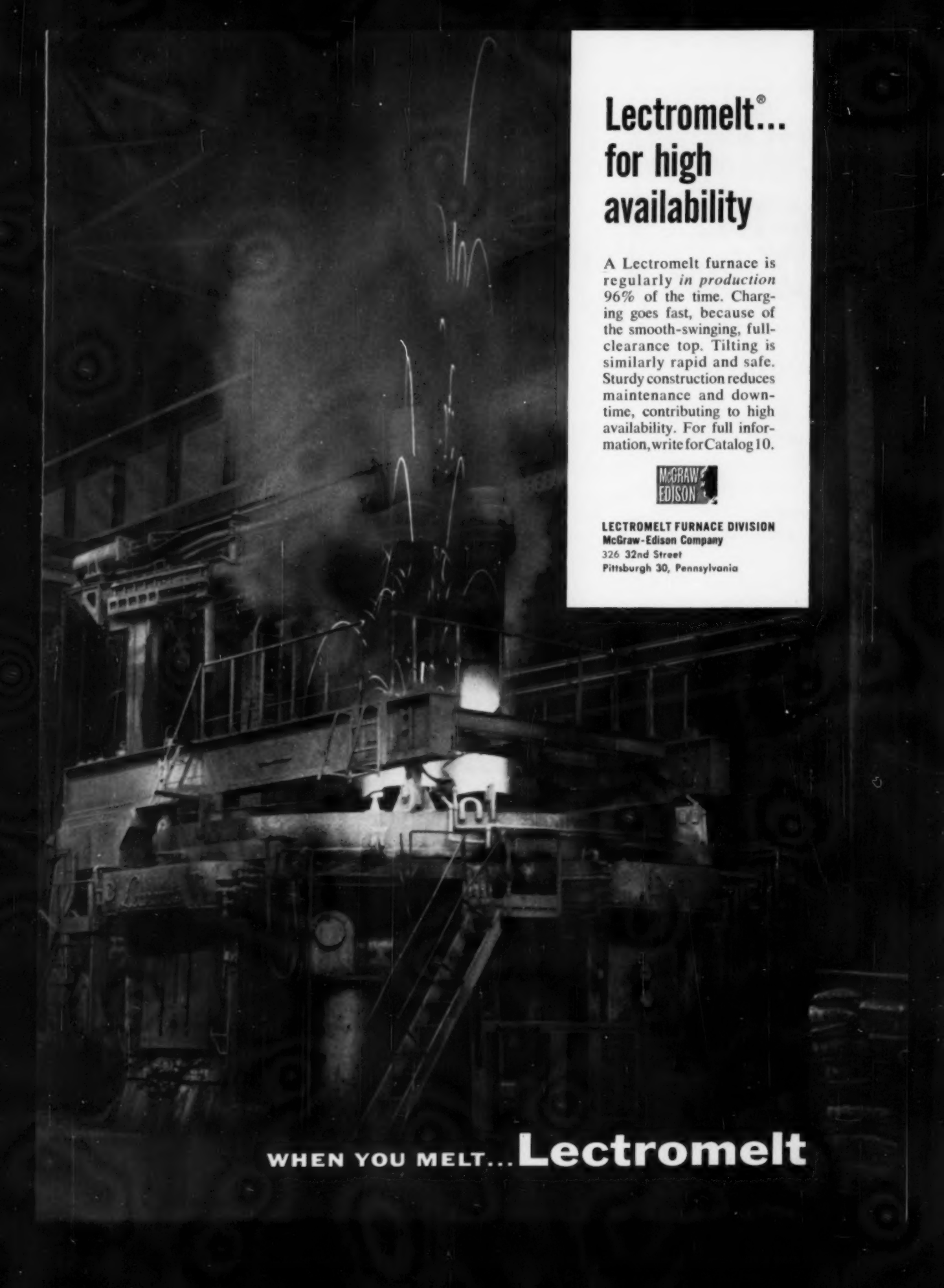

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Properties and Structure of Polymers, by Arthur V. Tobolsky, John Wiley & Sons, Inc., New York, 331 pp., $14.50, 1960. *Reviewed by Lawrence H. Van Vlack, University of Michigan.* •

If a metallurgist were to open this book to page 58, for example, he would feel at home immediately. On this page is a growth spiral on the surface of a single crystal as a result of a screw dislocation. He would also find the following text material. "The overall rate of formation of crystalline material is proportional to the rate of nucleation and also to the rate of growth around the nucleus. Nucleation rate, favored by supercooling, has a maximum value which occurs at a temperature appreciably below T_m. The growth rate, largely dependent upon diffusion, has a maximum value just very slightly below T_m. The overall rate of growth of crystalline material, being a product of these factors, also has a definite temperature at which it is minimum."

The above examples serve to indicate that a metallurgist can read a book on polymers. Prof. Tobolsky's book is concerned primarily with the mechanical properties of polymeric materials. This is illustrated by the six chapter titles which are 1) Elasticity and Viscosity, 2) Aspects of Polymeric Physics, 3) Mathematical Treatment of Linear Viscoelasticity, 4) Visoelastic Behavior of Polymers, 5) Chemical Stress Relaxations, and 6) Polymerization Equilibria. Only in the last two chapters are chemical formulae presented. These are more or less incidental. Rather, the presentation involves the physical chemistry principles that are familiar to the majority of present day metallurgists and ceramists who are research workers or graduate students. Those who do possess a physical chemistry background will find that the book can be readily followed. Also, those readers will become interested in making comparisons between the polymeric materials and those inorganic materials with which they constantly work.

Some metallurgists may object that Prof. Tobolsky's presentation is too mathematical and does not present sufficient experimental corroboration. It is doubtful that this may be considered to be an objection in this book which is intended to relate the mechanical properties of polymers to their structure. However, it is hoped that a subsequent effort will be made which will permit the interrelationships of structure and properties to be appreciated with less mathematical rigor. •

Metallic Corrosion Inhibitors by I. N. Putilova, S. A. Balezin, and V. P. Barannik. (Translated by G. Ryback and edited by E. Bishop.) Pergammon Press, 196 pp., $10.00, 1960. *Reviewed by Mars G. Fontana of Ohio State University.* •

This book is the only one I know that is devoted entirely to corrosion inhibitors. It is well done and would be a valuable book for persons engaged in combatting corrosion by decreasing the aggressiveness of environments and also for producers of inhibitors. The book contains a comprehensive literature survey, including many Russian articles that are probably not readily available to most of us in the US. American, Russian, and other foreign patents are included.

The book includes both theoretical and practical aspects of inhibition. The first two chapters cover classification and mechanisms. The last four chapters are separated into environments, namely acids; alkalies; water, salts, and atmospheric corrosion, including vapor phase inhibitors; and non-aqueous liquid media, i.e. fuels, oils, and other organics. The four short appendices include practical recommendations on pickling, rust removal, surface preparation, and vapor phase inhibitors. A separate index titled *Index of Inhibitors and Related Substances* is useful in that one can readily find information on a substance by chemical name or compound. An omission in the book is that several inhibitors, apparently widely used in the USSR are identified only by letters, i.e. CMH and PB-5. Literature references are given for these materials; so, perhaps their chemical nature is given in these Russian papers. At any rate, I did not identify them in the book.

The authors do not believe in classifying electrochemical inhibitors into anodic, cathodic, and mixed control, as has often been done. They prefer classifying inhibitors on the following bases: Type A—forms a protective layer on the metal surface; Type B—reduces the aggressiveness of the environment towards the metal, e.g. sodium sulfite removes dissolved oxygen from water and thereby reduces corrosion of steel; and Type AB—a combination of the actions of Types A and B. Type A is further broken down into IA—slows down corrosion but does not suppress it completely; IIA—delays the onset of corrosion; and IIIA—the protective layer formers that practically stop corrosion after a short time. Type IIA inhibitors are also

(Continued on page 235)

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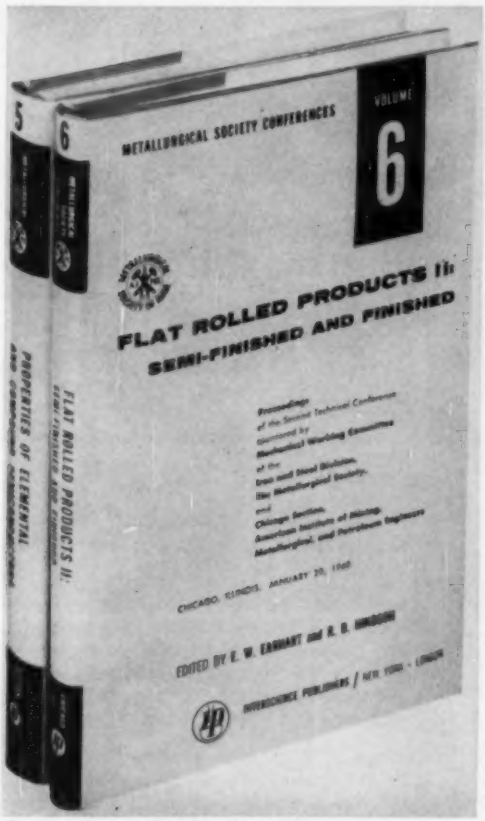

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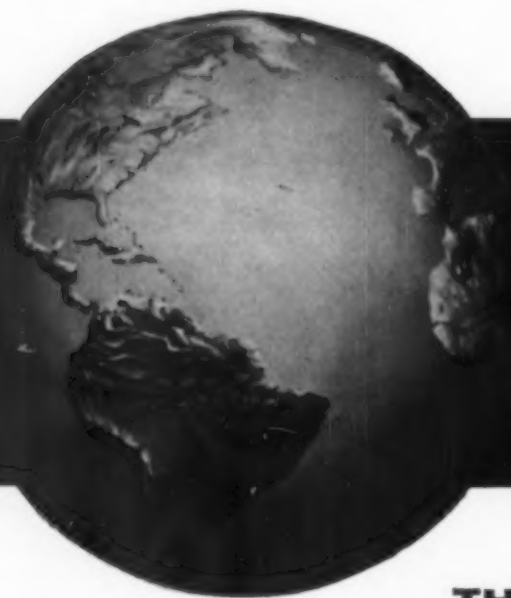

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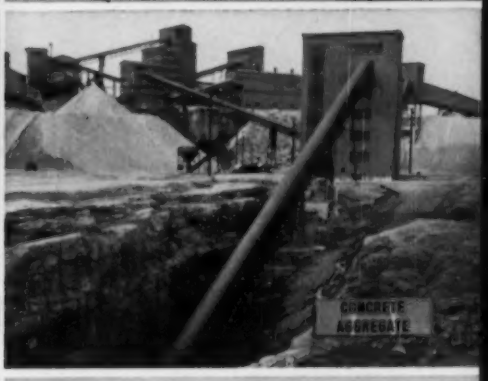

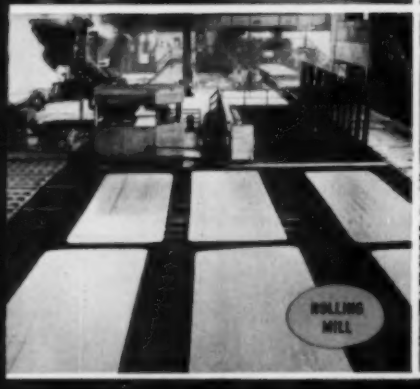

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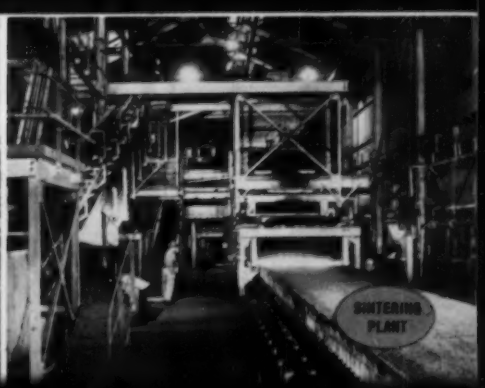

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editorial

A Tribute, A Welcome

Writing an editorial is not always the easiest task. "But this month was going to be an easy one", said we, looking over copy for the issue.

But then something else happened. An envelope arrived at home—a big envelope clearly marked AIME. "Ah", thought we, "another Annual Meeting announcement". But not so—it was a letter with the name Joseph L. Gillson imprinted at the bottom, but the name, Joe Gillson, written out. The letter went on to say,

"During the past year I have come to know many of you. I appreciate your competence and loyalty to AIME. In turn, many of you have learned that I am a man that speaks his mind. And I am speaking it now!

"You have heard (almost ad nauseum) about our commitment to give our $500,000 share toward building our new Engineering Building. Our sister societies have met, or almost met, their quotas—but we still need $80,000.

"Some of you haven't given a thin dime. Your fellow members who have given—including the younger men—have given generously. If you have already given, please give a little more. If you haven't given, please make up for it now."

And signed Joe Gillson. Well, to us he has always been *Joe Gillson* whether we meet him in full dress on the dais or in shirt sleeves at the wash basin. He has been called, "the workingest president of AIME", and we know whereof this comes, for few weeks pass without Joe Gillson's coming into the AIME offices, not just for a brief *tea* and then out. But Joe Gillson could be seen sitting at a desk working out matters with one or another of the AIME staff.

Yes, we have seen lots of Presidents of AIME, and good men they have been, but never before has there been a *Joe Gillson*. AIME will continue to need Joe Gillson, and we of the JOURNAL OF METALS hope that *Past President Gillson* will be seen here as frequently as *President Gillson*.

Our one consolation is that R. R. McNaughton—the 1961 AIME President—is also a great man. So, although we say a regretful "Farewell" to Joe, we give a hearty "Welcome" to Ron.

FWS

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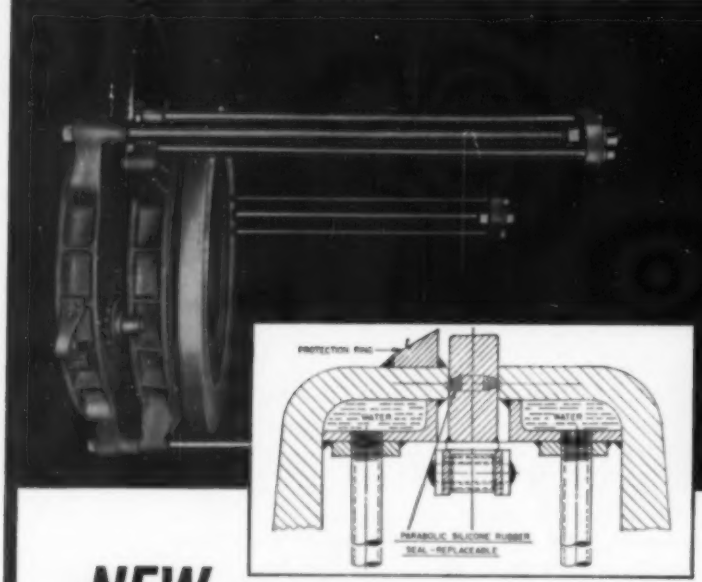
Water-Cooled, Silicone Rubber-Seated GOGGLE VALVE



NEW... GAS-TIGHT Service for High Pressure Furnaces

Designed for use between dustcatcher and washer, this valve features parabolic silicone rubber seats in the goggle plate, and water cooled flanges. Design provides a tighter, more gas-proof seal than is possible with metal-to-metal seals. *Write for Bulletin V-200.*

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education

Newsletter

South Dakota School of Mines and Technology has begun publication of the Mineral Industries Newsletter, which will be published semiannually and will cover mineral industries activities of the college.

A new million-dollar Mineral Industries Building at the School of Mines and Technology is expected to be ready for occupancy in September 1961.

Penn State

Pennsylvania State University will offer a short course on Solid State Mechanics June 11-23. The course is planned for research, design, and materials engineers in industrial, governmental, and educational institutions. The course may also be of interest to metallurgists, physicists and chemists who are engaged in various aspects of materials science, including the selection and evaluation of engineering materials. The fee for the course is $175. For further information write to The Conference Center, Pennsylvania State University, University Park, Pa.

Technical writing

The technical writer and his relation to the expanding uses of communication in modern industry and government will be the theme of the Ninth Annual Technical Writers' Institute scheduled for June 12-16, at Rensselaer Polytechnic Institute, Troy, N. Y. Experienced professional writers will join Rensselaer's technical writing staff in presenting the week-long Institute.

Subjects to be covered include the process of communication, including close analysis of the principles of editing; estimating reader attitudes; sessions on manuals and instructions; and discussions of technical publicity and article writing.

Inquiries should be sent to Prof. Jay R. Gould, Rensselaer Polytechnic Inst., Troy, N. Y.

Franklin Institute

A $2.5 million research building for the Franklin Institute will be built on a site adjacent to the Institutes main building in Philadelphia. The six-story structure will be constructed by the Philadelphia Industrial Development Corp., and will be occupied by the Institute on a long term lease.

When completed in late 1962, the building will enable the Institute to expand the personnel and activities of its research laboratories, which serve both private industry and Federal agencies.

METALGRAMS

UNION CARBIDE METALS

. . . news of "Electromet" ferroalloys and metals

MARCH, 1961

NEW COLUMBIUM ALLOY -- In recent months, interest has increased in columbium-treated carbon steels for structural applications. Small amounts of columbium sharply increase the yield and tensile strengths of these steels by promoting a fine-grained structure. The element also improves weldability. Highly soluble columbium additions to these steels can now be made with new high-silicon ferrocolumbium. By dissolving faster than regular ferrocolumbium, the new alloy promotes improved uniformity and control of columbium in steel. Ask your Union Carbide Metals representative for further information.

For more information circle 000 on page 00

* * *

ZIRCONIUM -- AN ACTIVE ELEMENT -- Zirconium added to steel readily combines with oxygen, sulphur, and nitrogen. It either removes these elements from the bath or renders them less harmful. For example, zirconium reduces the hot shortness of high-sulphur steels by tying up sulphur. It reduces age-hardening in deep-drawing steels by combining with nitrogen. Zirconium is also a strong grain refiner when more than 0.10 per cent is added to steel. Contact your Union Carbide Metals representative for more information. Also, ask for "The Elements That Surround Us: Zirconium" in the Fall 1960 issue of UNION CARBIDE METALS REVIEW.

For more information circle 000 on page 00

* * *

A WORLD-WIDE SEARCH -- The search never ends for high-grade ores, from which ferroalloys are made. Exploration teams of Union Carbide Ore Company search all parts of the world -- sometimes through tropical jungles, arid deserts, and unexplored rivers. Their goal: to discover new ore deposits to satisfy the growing demand for ferroalloys. Union Carbide's integrated mine-to-furnace operations assure a continuous supply of ferroalloys...when you want them. For the full story, write for the article, "From Earth to Hearth," in the Winter 1961 issue of UNION CARBIDE METALS REVIEW.

For more information circle 000 on page 00

* * *

THIS 'N' THAT -- Use of ferroalloys in pre-weighed bags allows: lower handling losses, improved inventory control, more accurate alloy additions, and better control of steel composition. Write for F-20,121 and F-20,138... "Simplex" low-carbon ferrochrome is a vacuum-processed alloy for stainless steel. It features rapid solubility, low price, and extremely low-carbon content. Write for F-20,118...Manganese costs for stainless steel can be sharply cut with ferromanganese-silicon. Write for F-20,093.

* * *

UNION CARBIDE METALS COMPANY, Division of Union Carbide Corporation, 270 Park Avenue, New York 17, N. Y. In Canada: Union Carbide Canada Ltd., Toronto.

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personals

Harry P. Croft has been elected vice president of Copper Range Co., in charge of research and sales engineering. He was formerly with Chase Brass & Copper Co., and Kennecott Copper Corp.

M. C. Flemings, assistant professor of metallurgy at M.I.T., has joined the staff of Modern Castings magazine as a contributing editor. **J. F. Wallace,** associate professor of metallurgical engineering, Case Institute of Technology will also be a contributing editor.

Eugene A. Gietzen has been appointed chief metallurgist at Bethlehem Steel Co.'s Lackawanna, N. Y., plant. He was previously assistant chief metallurgist.

Ernst M. Goldstein has joined the metallurgical department of Shieldalloy Corp. of Newfield, N. J. He was formerly with Metal and Thermit Corp.

A. A. Hendrickson is now associate professor in the metallurgical engineering department of Michigan College of Mining & Technology. He recently received his Ph.D. in the materials science dept. at Northwestern University.

Walter L. Keene has been appointed general manager of operations by Superior Steel div. of Copperweld Steel Co. He has been dircetor of research and metallurgy since 1945.

Daniel J. Lam is now assistant metallurgist in the metallurgy div. of Argonne National Laboratory where he will be engaged in measuring magnetic properties of alloys and intermetallic compounds.

Robert P. Lawrance has been appointed field engineer, nickel sales, by Alloy Metal Products, Inc. of Davenport, Iowa. He was formerly with National Lead Co.

David W. Levinson has been appointed metallurgical advisor at Armour Research Foundation. He was formerly assistant director of metals research.

David W. Lillie has been named manager of the materials application and evaluation section at General Electric Research Laboratory.

Robert McC. Maxwell has joined American Potash & Chemical Corp., as manager of manganese metal sales.

George C. Olson has been appointed works manager of Atlas Steels Ltd., Welland, Ont., Canada.

Niranjan M. Parikh has been named a senior metallurgist in the metals research div. at Armour Research Foundation.

Lloyd H. Paulsen is now general sales manager for the refractories div., Gladding, McBean & Co.

Thomas A. Prater has been appointed manager of the process laboratories unit of the General Electric Research Laboratory. He was formerly in the general engineering laboratory.

J. C. Rieger has been elected president of Wilson Marine Transit Co., to succeed the late A. T. Wood.

C. S. Simons is now superintendent of research, Manitoba div., of International Nickel Co., of Canada. He was formerly chief process engineer of Freeport Nickel Co.

G. T. Stowe has retired as vice president of E. J. Lavino & Co., after 30 years with the company. **F. R. Dykstra** has been named vice president and **H. N. Hall** has been named assistant vice president.

Arthur W. Thornton has been named director of engineering and research of the National Tube div., of U.S. Steel Corp. He was previously gen-

(Continued on page 235)

zone melting apparatus

Accurate control of motion accounts for the large number of users of the RSCo Zone Melting Apparatus.

Reliable motion patterns and rates for critical zone melting techniques may be selected easily on the Model 2471 • Slow motion is continuously adjustable from 0.22" to 2.2" and from 1.5" to 15" per hour, in either direction • Rapid motion is continuously adjustable from 2.4" to 24" per minute, in either direction.

Constancy of speed and long life of the drive unit are assured by new thyratron DC motor controller. A new ball-bearing lead-screw smoothly transmits uniform motion to the carriage.

Many conveniences contribute to versatility in Model 2471 • Large carriage capacity for heaters, cooling coils, etc., on 14" x 7½" platform • Long excursion of carriage, 26" • Horizontal, tilted, or vertical operation • Separate operation of Drive Unit for user-built applications.

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OLP developments

Commercial application of the OLP—oxygen-lime powder—process is being rapidly extended in France as a result of continued activity and improvement by its developers, the Institut de Recherches de la Sidergie (IRSID). A 30-ton OLP converter has been operating on a three shift basis at Dillingen in the Saar using high-phosphorus hot metal. Metallurgical and other technical features have resulted in a lining life of 200 heats. Dephosphorization is well under control, and no difficulty is experienced in the regular production of low-carbon steels with low phosphorus. Recent developments provide assurance of making carbon steels up to at least 0.5 pct C from 1.8-pct P hot metal. In France at Denain, USINOR has just started operation of a 60-ton converter for blowing high phosphorus hot metal. Lime powder rates of half a ton per min are reached. At the new plant in Dunkirk, now under construction, hematite hot metal will be refined in 140-ton converters by the OLP process.

Improve Va ductility

The ductility of vanadium is improved by alloying it with yttrium metal or one of a series of rare earth metals, according to a research program recently completed at the Metallurgical div., Denver Research Institute, University of Denver.

The rare earth metals act as a scavenger to remove oxygen and nitrogen impurities, making possible greater than 98 pct reduction by direct rolling without the usual intermediate annealing operations. Additions of only 1 wt pct Y resulted in optimum ductility. It was pointed out that the solubility relationships of the rare earth-vanadium alloy systems are such that, above the melting point of the alloy, a rare-earth-metal-rich liquid separates from the liquid-vanadium matrix, fluxing out the oxygen and nitrogen impurities.

The Metallurgical div. is also engaged in work using rare earth metals for decreasing hardness and increasing ductility of molybdenum.

Strategic licenses

Strategic Materials Corp. has signed two new process licensing agreements. These and other recent developments were announced by Frank W. Chambers, president of the Corp., at a recent stockholders meeting. The two new agreements for use of the company's Strategic-Udy process involve the production of 25,000-tons-per-year of ferrochrome in the Philippines and the production of 150,000-tons-per-year of iron at Kingston, Ont., Canada. There is also the possibility that negotiations will be completed in the near future for the building of 100,000-ton-per-year pig iron plant in India which will use the Strategic-Udy process. For descriptions of the process, see JOURNAL OF METALS, March 1957, p. 340; May 1959, p. 311; December 1959, p. 829; and February 1961, p. 135.

Ti pressure vessels

Three major missile systems—Atlas, Titan, and Polaris—have recently switched from heavier alloy steels to titanium pressure vessels. The approx 40 pct weight saving realized with titanium has long been considered advantageous, but the metal's lack of *fabricability* has hindered its application. Recent developments, which are said to assure sound welds at working pressures of 10,000 psi, under extreme conditions of temperature, vibration, and load are apparently the key to the switchover. Papers presented at a recent symposium on *Titanium vs Steel and Aluminum in Pressure Vessels in Hydrospace, Aerospace, and Space* can be found in this issue of Journal of Metals, p. 195.

New Arizona plant

Arkota Steel Co. is currently building a $1-million plant on an 80 acre site in Coolidge, Ariz., located some 100 mi from Phoenix. Nearby is a 40,000 acre Government tract of iron-bearing sand, reputedly containing about ½ billion tons of iron. The plant will be the first in the US to utilize the direct reduction process developed by J. D. Madaras for converting iron-bearing sands to sponge iron on a commercial basis. The Madaras process is a batch operation employing low-cost natural gas as the reducing agent. Black sand, containing from 5 to 15 pct Fe, will be magnetically beneficiated and then reduced to a 95-pct pure sponge iron in a gas-fired retort. The sponge iron produced can then be melted and refined in an electric furnace into commercial grades of steel.

World's largest BF

The USSR claims to have blown-in the world's largest blast furnace at the Krivoi Rog steelworks in the Ukraine. Although the report did not mention the furnace's capacity, it is claimed that by using natural gas and a superheated oxygen-enriched blast, the highest efficiency in the world could be achieved. Indications are that this furnace may be one of five that the USSR intended building during 1960. Previous reports concerning these furnaces, predicted a daily output of 4500 ton of pig iron per day, from each of the 32-ft hearth diam furnaces.

New tool steel

The Crucible Steel Co. of America has developed a new grade of high speed steel —*Rex 49*—designed to provide greatly increased tool life in machining hard-to-cut metals. The steel, currently undergoing evaluation, can be heat treated to hardnesses of R.67 to 69. In tests on many hard-to-machine metals, it has outperformed other high speed steels, increasing tool life two to four times. In the cutting of more conventional materials, its use permits increases in speed, feed, or depth of cut.

REPORTER

REPORTER

New magnetic alloys

The Precision Metals & Electronics div. of the Hamilton Watch Co. recently announced the development of a new line of magnetic alloys called *Vapalloys* which are ultra high-purity alloys used as a source material to produce magnetic thin films for computer memories. The alloys are produced by vacuum induction melting designed to keep residual gas content at a minimum. Hydrogen and nitrogen are usually kept to less than 1 ppm. Oxygen runs slightly higher, since solid deoxidizers are avoided. Some other impurities are: 1 to 10 ppm Ca, 1 to 10 ppm Si, 3 to 30 ppm Mg, 1 to 3 ppm Al, 3 to 30 ppm Mn, and 5 to 40 ppm C. *Vapalloys* are in use in Univac thin-film computers which are the first of Remington Rand's *third-generation* computers. Thin magnetic films are said to give the fastest memory access time—1-billionth of a sec—of any commercial computers available.

New Cb_2O_5 pilot plant

Final mill tests have been completed by Columbium Products, a subsidiary of Coulee Lead & Zinc Mines Ltd. and Headway Lake Gold Mines Ltd., on a 150-ton bulk ore sample from its Oka, Que., Canada, columbium property. In view of the highly satisfactory results, the company has started preliminary design of a 250-tpd pilot plant to process the ore. The mill is expected to produce approx 750,000 lb of Cb_2O_5 annually. In the final mill test, the company, using its patented floatation process, produced concentrates grading from 45 to 48 pct Cb_2O_5 with overall recovery of approx 85 pct.

Columbium mining officials believe that the process is the most advanced technique yet developed for the concentration of columbium minerals of the Oka type—predominantly the pyrochlore mineral. In the process, ore is put through a preliminary float with magnetic separation which conditions the pulp for subsequent steps and eliminates 4 pct of the feed as waste. About 95.2 pct of the feed is rejected as waste in the primary, secondary, and tertiary floats. The remaining fraction is treated by tabling to produce a 48 pct columbium pentoxide material. Fine columbium-bearing particles in the table reject are recovered in another float, producing a final concentrate of approx 45 pct Cb_2O_5. An important factor in the process is that, after the primary float, tailings can be returned to any point in the circuit for additional recovery without any retreatment.

Columbium Mining is also conducting a number of processing programs on concentrates in Ottawa. These involve treatment by chloridization, sulfuric-acid leaching and hydrolysis for the production of columbium and ferrocolumbium. Other companies are also interested in the Oka mining district, see January 1961 issue of JOURNAL OF METALS p. 16.

Uranium research

A $1.25-million research program has been inaugurated to boost Canada's uranium industry. Headed by Frank Forward, Professor of Metallurgy, University of British Columbia, the program is sponsored by six major uranium companies which have set up the Canadian Uranium Research Foundation. Professor Forward, developer of the ammonia leach process for the recovery of nickel, hopes to follow the same lines as the research program initiated by the International Nickel Co. shortly after World War I. At that time, nickel demand was falling off sharply, and the research program developed many new uses for the metal and led to an increased world market. (On p. 221 application of Prof. Forward's leaching process to copper is discussed.)

Garfield modernization

A $5-million modernization program is being carried out at the Garfield smelter of the Kennecott Copper Corp. with completion scheduled for June 1962. Major innovations include changing the reverberatory furnaces to a different arch suspension so that they can accept green concentrates. This will mean elimination of roasting at the smelter. The installation of a double-direction car dumper will permit railroad cars to dump in two directions, thus facilitating segregation of materials. Ultimately, concentrates will be conveyed by belts to the storage building. In addition, automatic blending of fluxes will be effected to prepare a more uniform furnace charge.

Largest vacuum furnace

The world's largest consumable electrode vacuum furnace has been successfully placed in operation at the Watervliet works of Allegheny Ludlum Steel Corp. The new furnace will produce ingots up to 50 in. in diam weighing approx 60,000 lb. They will be the largest vacuum-melted steel ingots commercially available. The Lectromelt div. of McGraw-Edison Co. built the furnace, which is to supply metal to builders of aircraft, missiles, and rockets.

New Re division

Chase Brass & Copper Co., a div. of Kennecott Copper Corp., recently announced the formation of a rhenium division. Methods for recovery and purification of rhenium were developed at Kennecott's research center in Salt Lake City. Chase and Kennecott's research groups worked out production processes for obtaining the extremely dense, silver-colored powder, a byproduct of roasting molybdenum sulfide. Methods for fabricating the wrought metal were also developed. For a brief description of the process, see the October 1960 issue of JOURNAL OF METALS, p. 769.

Rhenium has wide application in the electronic, electrical, and aerospace fields.

Programs

National Open Hearth Steel Committee and Blast Furnace, Coke Oven, and Raw Materials Committee

The Sheraton Hotel, Philadelphia, will be the scene of the 44th conference held April 10 through 12, 1961. Registration will be in the Delaware Valley Suite, 3 to 9 pm, Sunday, April 9; 8 am to 5 pm, Monday, April 10; 8 am to 5 pm, Tuesday, April 11; and 8 am to 4 pm, Wednesday, April 12. A special train for the plant trip to Bethlehem Steel Co.'s Sparrows Point plant will leave from the Philadelphia Suburban Station adjacent to the Sheraton Hotel.

NATIONAL OPEN HEARTH STEEL CONFERENCE

Monday, April 10

General Session

9:30 to 10:15 am — **Ballroom East and West**

Welcoming Remarks: *L. W. Moore*, Assistant General Manager, Wheeling Steel Corp., Steubenville, Ohio.
Announcements and Reports
McKune Award Paper

Basic Operations

10:15 am to 12:15 pm — **Ballroom East and West**

Chairmen: *C. F. Henzelman*, Assistant Superintendent, Hot Metals Division, Granite City Steel Co., Granite City, Ill..
J. Kirkpatrick, Assistant to Vice President, Operations, Youngstown Sheet and Tube Co., Youngstown, Ohio.

Potential of the Open Hearth: *George Ferris*, Operations Manager, Ingot Production and Primary Mills, Ford Motor Co., Dearborn, Mich.

Some Aspects of High-Oxygen Practice at Great Lakes: *Ralph Duffett*, Superintendent of Open Hearths and Bessemers, Great Lakes Steel Corp., Ecorse, Detroit, Mich.

Comparison of Practices With Oxygen-Fuel Burners and Oxygen Lances: *T. B. Winkler*, Division Head, Process Metallurgy Section, Research Department, Bethlehem Steel Corp., Bethlehem, Pa.

Discussion: John Glasgow, Open Hearth Superintendent, Jones & Laughlin Steel Corp., Cleveland, Ohio
E. Goodin, Open Hearth Superintendent, Granite City Steel Co., Granite City, Ill.
J. Smith, Open Hearth Superintendent, Republic Steel Corp., Warren, Ohio.

Acid Operations

10:15 am to 12:15 pm — **Penn Center Room**

Chairmen: *G. A. Taylor*, Superintendent Open Hearth, Erie Forge and Steel Corp., Erie, Pa.
T. D. Collins, Foreman, Open Hearth, Mackintosh-Hemphill Division, E. W. Bliss Co., Midland, Pa.

Monday, April 10, Continued

Some Problems Encountered in the Use of Deuterium as a Tracer Element for Hydrogen In Steel: *J. H. Dudas*, Research Engineer, University of Pittsburgh, Pittsburgh, Pa., and *R. C. McCoy*, Research Engineer, Acid Open Hearth Research Association, Inc., Pittsburgh, Pa.

Preparation of Steel With Low-Gas Content in the Acid Open Hearth Process: *G. R. Fitterer*, Director of Research, and *R. C. McCoy*, Research Engineer, Acid Open Hearth Research Association, Inc., Pittsburgh, Pa.

Deoxidation by Vacuum: *E. Dyble*, Metallurgical Engineer, and *G. A. Taylor*, Superintendent, Melting Department, Erie Forge and Steel Corp., Erie, Pa.

Acid Bessemer Process

10:15 am to 12:15 pm — **Constitution and Independence Rooms**

Chairmen: *J. N. Albaugh*, Superintendent, Jones & Laughlin Steel Corp., Aliquippa, Pa.
A. B. Wilder, Chief Metallurgist, National Tube Division, U. S. Steel Corp., Pittsburgh, Pa.

Formation and Suppression of Smoke in Pneumatic Steelmaking Processes: *G. W. P. Rengstorff*, Assistant Chief, Metals Science Group, Battelle Memorial Institute, Columbus, Ohio.

Recent Developments in the Basic Bessemer (Thomas) Process in Europe: *G. M. Yocom*, Assistant to General Manager, Wheeling Steel Corp., Steubenville, Ohio.

Round Table Discussion:
Moderator: *A. B. Wilder*, Chief Metallurgist, National Tube Division, U. S. Steel Corp., Pittsburgh, Pa.
Tentative Agenda—

Safety in Bessemer Shop
Hot Metal—Quality of Iron
Refractories for the Converter—Mixers and Ladles
Vessel Operation—Blowing and Pouring Practices
New Developments

Operating Metallurgy I—Manufacture of Large Rimming and Bottle Top Steel Ingots for Sheet Applications

2:00 to 5:00 pm — Ballroom West

Chairmen: *Michael Tenenbaum*, Assistant General Manager, Technical Services, Inland Steel Co., East Chicago, Ind.
R. D. Hindson, Assistant Chief Metallurgist, The Steel Co. of Canada, Ltd., Hamilton, Ontario, Canada.

Solidification of Open Hearth Steels:
- a. Some Origins of Structures in Rimmed and Partially Killed Ingots: *B. M. Larsen*, Assistant Director, Fundamental Research Laboratory, U. S. Steel Corp., Monroeville, Pa.

Manufacture of Large Rimming Steel Ingots:
- a. Metallurgical Problems Encountered in the Manufacture of Large Rimming Steel Ingots: *H. F. Lesso*, Senior Steel Plant Metallurgist, Great Lakes Steel Corp., Ecorse, Detroit, Mich.
- b. Metallurgical Aspects in the Manufacture of Large Rimming Steel Ingots: *B. W. Bowen*, Republic Steel Corp., Cleveland, Ohio.

Manufacture of Large Mechanically Capped Ingots:
- a. Use of Large Bottle Top Ingots for the Manufacture of Flat Rolled Products: *M. Tarris* and *Leonard Pucker*, Granite City Steel Co., Granite City, Ill.
- b. Adoption of Large Mechanically Capped Ingots to Sheet Applications: *L. R. Walker, J. O. Mack*, and *J. F. Georgiadis*, Fairless Works, U. S. Steel Corp., Fairless Hills, Pa.

Refractories I

2:00 to 5:00 pm — Pennsylvania East and West Rooms

Chairmen: *M. E. Nickel*, Assistant Superintendent, Open Hearth, Wisconsin Steel Division, International Harvester Co., Chicago, Ill.
R. F. Urban, Assistant to Superintendent, Open Hearth and Bessemer, Sparrows Point Plant, Bethlehem Steel Co., Sparrows Point, Pa.

Prefabrication of Open Hearth Ends and Ports:
- a. Prefabrication of Basic Open Hearth Ends and Port Roofs: *L. R. Lattimore*, Superintendent, Masonry Department, Lone Star Steel Co., Lone Star, Texas.
- b. Prefabrication Sections in a Maerz-Boelens Type Open Hearth Furnace: *L. B. Lindemuth*, Open Hearth Superintendent, Keystone Steel and Wire Co., Peoria, Ill.

Ladle Gunning: *D. Saylor*, General Foreman, Masonry Department, Ford Motor Co., Dearborn, Mich.

A Refractories Quality Control Program for Steel Plants: *A. Sontz*, General Supervisor, Ceramics Development, and *E. C. Rudolphy*, Assistant Chief Metallurgist, South Works, U. S. Steel Corp., Chicago, Ill.

Discussion: *E. B. Snyder*, Open Hearth Superintendent, Phoenix Steel Corp., Claymont, Del.

Basic Oxygen Steelmaking Refractories:
- a. Wear Patterns of L-D Vessel Linings: *J. R. Atkinson*, Superintendent Steelmaking, Dominion Foundries and Steel, Ltd., Hamilton, Ontario, Canada
- b. Developments in Lining Refractories for the Basic Oxygen Process: *J. N. Albaugh*, Superintendent Steel Production, Aliquippa Plant, Jones & Laughlin Steel Corp., Aliquippa, Pa.
- c. Techniques of Lining L-D Vessels: *F. C. Muttitt*, Assistant Superintendent, Masonry, Algoma Steel Corp., Sault Ste. Marie, Ontario, Canada.

Refractories (II)

9:30 am to 12:15 pm — Ballroom West

Chairmen: *E. B. Snyder*, Open Hearth Superintendent, Phoenix Steel Corp., Claymont, Del.
George Grosvenor, Superintendent Open Hearth, Colorado Fuel and Iron Corp., Pueblo, Colo.

A. Basic Brick Today and Tomorrow.
Current Status of Basic Brick Technology: *G. R. Eusner*, Chief Refractory and Mineral Technology Division, Applied Research Laboratory, U. S. Steel Corp., Monroeville, Pa.

Basic Brick for the Future: *H. M. Kraner*, Division Head, Ceramics, Development and Research Department, Bethlehem Steel Corp., Bethlehem, Pa.

Discussion: *B. L. Dorsey*, Ceramic Engineer, Jones & Laughlin Steel Corp., Pittsburgh, Pa.

B. Basic Roof Life as Affected by Combustion Practices.
Productivity and Refractory Consumption for Various Combinations of Fuel and Oxygen Rates: *T. W. Trumper*, Practice Engineer, Open Hearth, Steel Co. of Canada, Ltd., Hamilton, Ontario, Canada.

Discussion: *E. B. Snyder*, Open Hearth Superintendent, Phoenix Steel Corp., Claymont, Del.
T. B. Winkler, Division Head, Process Metallurgy Section, Research Department, Bethlehem Steel Corp., Bethlehem, Pa.

C. Basic Roof Maintenance.
Patching and Maintaining Basic Roofs: *Keith Bartels*, Superintendent, Masonry Department, Fairless Works, U. S. Steel Corp., Fairless Hills, Pa.

Construction, Maintenance, and Patching of Basic Roofs: *Frank Pikus*, Superintendent, Masonry Department, Columbia-Geneva Steel Division, U. S. Steel Corp., Provo, Utah.

Patching Techniques for Basic Roofs: *F. J. La Rocca*, Ceramic Engineer, Colorado Fuel and Iron Corp., Pueblo, Colo.

Basic Oxygen Process

9:30 am to 12:15 pm — Ballroom East

Chairmen: *J. R. Atkinson*, Superintendent, Steelmaking, Dominion Foundries and Steel, Ltd., Hamilton, Ontario, Canada.
M. J. Smith, Division Superintendent, Primary Production, Kaiser Steel Corp., Fontana, Calif.

Introductory Remarks:
A. B. Wilder, Chief Metallurgist, National Tube Division, U. S. Steel Corp., Pittsburgh, Pa.

The Colorado Fuel and Iron Corporation's Basic Oxygen Steelmaking Plant: *George Grosvenor*, Superintendent Open Hearth, Colorado Fuel and Iron Corp., Pueblo, Colo.

New Facilities: *John Glasgow*, Open Hearth Superintendent, Jones & Laughlin Steel Corp., Cleveland, Ohio.

Air Pollution Control in Oxygen Steelmaking: *J. H. Smith*, Director, Air Control and Research, Kaiser Steel Corp., Fontana, Calif.

Design and Construction of Great Lakes Basic Oxygen Plant: *Richard Morgan*, Assistant Superintendent, No. 2 Open Hearth, Great Lakes Steel Corp., Ecorse, Detroit, Mich.

Panel Discussion on Automation:
C. C. Benton, Division Superintendent, Algoma Steel Corp., Sault Ste. Marie, Ontario, Canada.
J. R. Atkinson, Superintendent, Steelmaking, Dominion Foundries and Steel Co., Ltd., Hamilton, Ontario, Canada.
Representative of Acme Steel Co.
Representative of Jones & Laughlin Steel Corp.

Operating Metallurgy (II)

2:00 to 5:00 pm — Ballroom West

Chairmen: *H. B. Emerick*, Director—Technical Services, Jones & Laughlin Steel Corp., Pittsburgh, Pa.
A. A. Kappenhagen, General Superintendent, Chicago District, Republic Steel Corp., Chicago, Ill.

Process Kinetics of Basic Oxygen Steelmaking: *W. O. Philbrook*, Professor of Metallurgical Engineering, Carnegie Institute of Technology, Pittsburgh, Pa.

Discussion: *J. F. Elliott*, Professor of Metallurgy, Massachusetts Institute of Technology, Cambridge, Mass.

Relation Between Inclusions, Oxygen Contents, and Defects in Seamless Tube Steels: *N. L. Samways*, Research Supervisor, and *E. J. Paliwoda*, Senior Research Engineer, Jones & Laughlin Steel Corp., Pittsburgh, Pa.

Discussion: *R. W. Farley*, Director, Process Development, Republic Steel Corp., Chicago, Ill.
I. A. Sirel, Supervisor, Quality Control Department, Open Hearth and Rolling Mills, Youngstown Sheet and Tube Co., East Chicago, Ind.

Behavior of Columbium in Liquid Steel: *R. W. Joseph*, Supervising Metallurgist, and *J. T. Mareta*, Metallurgist, Metallurgical Department, Inland Steel Co., East Chicago, Ind.

Discussion: *J. W. Farrell*, Metallurgical Engineer, Technology Department, Union Carbide Metals Co., Niagara Falls, N. Y.

Exothermic Sideboard Hot Tops: *W. E. Bayers, Jr.*, Chief Metallurgist, and *C. D. Boyle*, Chief Process Metallurgist, Edgar Thomson Works, U. S. Steel Corp., Braddock, Pa.

Discussion: *H. W. Patloger*, Area Supervisor, Colorado Fuel and Iron Corp., Pueblo, Colo.
T. E. Roberts, Chief Observer, Alan Wood Steel Co., Conshohocken, Pa.

Combustion and Operations

2:00 to 5:00 pm — Ballroom East

Chairmen: *F. R. Smith*, Jr., Division Superintendent, Steel Production, Gary Steel Works, U. S. Steel Corp., Gary, Ind.
John Glasgow, Open Hearth Superintendent, Jones & Laughlin Steel Corp., Cleveland, Ohio.

Rates of Oxidation and Heating of Scrap in Open Hearth Furnaces: *P. J. Koros*, Senior Research Engineer, *B. G. Nordstrom*, Research Engineer, and *J. A. Smik*, Research Engineer, Jones & Laughlin Steel Corp., Pittsburgh, Pa.

High Usage of Natural Gas: *W. H. Kahl*, Assistant Superintendent No. 2 Open Hearth, Inland Steel Co., East Chicago, Ind.

Discussion: *S. Penny*, Superintendent, Open Hearth, Tennessee Coal and Iron Division, U. S. Steel Corp., Fairfield, Ala.

Tuesday, April 11, Continued

Combustion Control in Open Hearth Furnaces: *R. E. Stoll*, Chief Process Metallurgist, *G. C. Primm*, Superintendent, Fuel Utilization, and *E. C. Rudolphy*, Assistant Chief Metallurgist, South Works, U. S. Steel Corp., Chicago, Ill.
Discussion: *B. Bevelheimer*, Jones & Laughlin Steel Corp., Pittsburgh, Pa.

Pouring Pit Maintenance: *W. Redmond*, General Foreman, Casting Department, Republic Steel Corp., Buffalo, N. Y.

Ingot Molds and Stools Made at Lone Star Steel Company: *R. C. Harrell*, Superintendent of Foundries, Lone Star Steel Co., Lone Star, Texas.

Discussion: *K. Kansikas*, Superintendent, Shops and Foundry, Algoma Steel Corp., Sault Ste. Marie, Ontario, Canada

Rebuild of #10 Open Hearth Furnace, #1 Open Hearth Shop: *A. Tunia*, Superintendent of Construction, Great Lakes Steel Corp., Ecorse, Detroit, Mich.

Cold Metal and Basic Foundry

2:00 to 5:00 pm — Hall of Flags East

Chairmen: *S. L. Fredericks*, Chief Metallurgist, American Steel Foundries Co., Granite City, Ill.
C. J. McElhaney, Superintendent, Open Hearth, Pittsburg Works, Columbia-Geneva Steel Division, U. S. Steel Corp., Pittsburg, Calif.

Methods for Evaluating Refractories: *F. H. Hohn*, Assistant to the Works Manager and Chief Metallurgist, Scullin Steel Co., St. Louis, Mo.

Use of the Natural Gas-Oxygen Burner in All-Cold Metal Open Hearth Furnaces: *E. W. Ganslein*, The Buckeye Steel Casting Co., Columbus, Ohio.

Improved Chromium Recovery and Control in the Basic Open Hearth: *D. R. Haines*, Assistant to the Director of Research, and *A. K. Wilson*, Technical Engineer, General Steel Castings Corp., Eddystone, Pa.

Round Table Discussion: Intermittent Operations and Week-End Shutdowns
G. W. Teskey, Superintendent, Open Hearth, Bethlehem Pacific Coast Steel Corp., South San Francisco, Calif.
C. J. McElhaney, Superintendent Open Hearth, Pittsburg Works, Columbia-Geneva Steel Division, U. S. Steel Corp., Pittsburg, Calif.
W. H. Steinheider, General Foreman, Open Hearth, Sheffield Division, Armco Steel Corp., Kansas City, Mo.
W. F. Low, Project Engineer, John A. Roebling's Sons Division, Colorado Fuel and Iron Corp., Trenton, N. J.

Annual Fellowship Dinner

Tuesday, April 11

6:30 pm—Pennsylvania Room

Reception and Cocktail Party for dinner guests

7:00 pm—Ballroom

Annual Fellowship Dinner

Toastmaster: *C. Thompson Stott*, General Manager, Sparrows Point Plant, Bethlehem Steel Company.

Speaker: *Admiral Arthur W. Radford*, United States Navy, Retired (Former Chairman, Joint Chiefs of Staff)

Programs/

BLAST FURNACE, COKE OVEN, AND RAW MATERIALS CONFERENCE

Monday, April 10

Blast Furnace Practice Session

9:00 am to 12:00 m — Pennsylvania West Room

Chairmen: *D. H. Regelin*, Assistant Chairman, Operating Committee, Iron Production, U. S. Steel Corp., Pittsburgh, Pa.
L. W. Butz, Assistant Superintendent, Blast Furnace Division, Bethlehem Plant, Bethlehem Steel Co., Bethlehem, Pa.

Welcoming Remarks: *James Chisholm*, Superintendent, Central Furnaces and Docks, American Steel and Wire Division, U. S. Steel Corp., Cleveland, Ohio.

Effect of Screened Sinter on Furnace Productivity: *N. D. Macdonald*, General Works Manager, Workington Iron and Steel Co., Ltd., Workington, Cumberland, England.

Operating Results Using Taconite Pellets in Armco's Middletown No. 3 Blast Furnace: *K. R. Haley*, Superintendent, Blast Furnaces, Armco Steel Corp., Middletown, Ohio.

Use of Blast Furnace Probes: *J. C. Agarwal*, Research Associate, *H. R. Pratt*, Assistant Technologist, Applied Research Laboratory, U. S. Steel Corp., Monroeville, Pa., and *R. H. White*, Division Superintendent, Blast Furnaces, Coke and Chemical Works, Fairless Works, U. S. Steel Corp., Fairless Hills, Pa.

Coal Session

9:00 am to 12:00 m — Pennsylvania East Room

Chairmen: *J. S. Mohr, Jr.*, Assistant Superintendent, No. 2 Coke Plant, Inland Steel Co., East Chicago, Ind.
R. R. Campbell, Division Superintendent, Coke and Coal Chemicals, U. S. Steel Corp., Gary, Ind.

Bench-Scale Experiments in Developing Anthracite Metallurgical Briquets: *W. S. Sanner*, Supervising Chemical Engineer, *R. E. McKeever*, Chemical Engineer, and *J. W. Eckerd*, Chief, Branch of Utilization and Preparation, Anthracite Research Center, U. S. Bureau of Mines, Schuylkill Haven, Pa.

Recent Developments in Coal Petrography: *N. Schapiro*, Supervising Technologist, Anthracology Section, *R. J. Gray*, Senior Technologist, Anthracology Section, and *G. R. Eusner*, Division Chief, Refractory and Mineral Technology Division, Applied Research Laboratory, U. S. Steel Corp., Monroeville, Pa.

The Maple Creek Preparation Plant: *L. U. Anderson*, General Plant Foreman, Maple Creek Preparation Plant, U. S. Steel Corp., Uniontown, Pa.

Storage of High-Volatile Coal at Pueblo Plant of Colorado Fuel and Iron Corporation: *J. R. Purdy*, Assistant Superintendent, By-Product Coke Plant, The Colorado Fuel and Iron Corp., Pueblo, Colo.

Monday, April 10, Continued

Blast Furnace Theory Session

2:00 to 5:00 pm — Ballroom East

Chairmen: *H. W. Meyer*, Research Supervisor, Graham Research Laboratory, Jones & Laughlin Steel Corp., Pittsburgh, Pa.
M. O. Holowaty, Chief Research Engineer, Inland Steel Co., East Chicago, Ind.

Idealized Heat Transfer From a Gas Stream to Granular Solids: *J. F. Elliott*, Professor of Metallurgy, and *J. C. Humbert*, Massachusetts Institute of Technology, Cambridge, Mass.

Significance of Size Distribution, High-Temperature Strength, and Reactivity of Coke in the Blast Furnace and Cupola: *H. Echterhoff*, Chief Engineer, Carbonization Research, and *W. Peters*, Section Manager, Processing and Technology Dept. Bergbau-Forschung, G.m.b.H. Essen-Kray, Germany.

Theoretical Considerations on the Injection of Auxiliary Fuels into the Blast Furnace: *A. M. Decker*, Chief Research Engineer, Centre National de Recherches Metallurgiques, Abbaye Du Val-Benoit, Liege, Belgium.

Coal Chemicals Session

2:00 to 5:00 pm — Constitution and Independence Rooms

Chairmen: *E. V. Schulte*, Assistant Manager, Development, Engineering and Construction Division, Koppers Co., Inc., Pittsburgh, Pa.
F. H. Armbrust, Superintendent, Coke Plant, Republic Steel Corp., Youngstown, Ohio.

Diammonium Phosphate—From Phosphate Rock and Coal to Fertilizer and Fire-Retardant: *W. G. Schulze*, Superintendent, Coke and Coal Chemicals Plant, Kaiser Steel Corp., Fontana, Calif.

Removal of Thiophene Sulfur From Benzene and Toluene by Means of Sulfuric Acid Washing: *Richard Muder*, Senior Scientist, *Joseph Kovacic*, Scientist, and *George Bretz*, Scientist, Research Department, Koppers Co., Inc., Verona, Pa.

Ammonia and Urea From Steelmaking By-Products: *S. J. Viron*, Assistant Technical Director, Cyanamid of Canada, Hamilton, Ontario, Canada.

Steam Economy for Wash Oil Stripping Systems: *Y. C. Chang*, Technologist, Applied Research Laboratory, U. S. Steel Corp., Monroeville, Pa.

Monday, April 10, Continued

Iron Ore Reduction Session

2:00 to 5:00 pm — Penn Center Room

Chairmen: *Henry Epstein*, Practice Engineer—Ironmaking, Research Dept., Bethlehem Steel Co., Bethlehem, Pa.
John Griffen, Coal and Coke Consultant, Pittsburgh, Pa.

Allis-Chalmers Agglomeration—Reduction Process: *T. G. Kirkland*, Supervisor, Applied Research, *C. L. Sollenberger*, Supervisor, Process and Mechanical Research, *J. L. Platner*, Engineering Scientist in Charge, Applied Research, and *W. W. Edens*, Assistant Director, Research Division, Allis-Chalmers Manufacturing Co., Milwaukee, Wisc.

Kinetics of Reduction of Sintered Iron Ore With Minor Compound Additions: *J. H. Cox*, Research Associate, and *H. U. Ross*, Associate Professor of Metallurgical Engineering, University of Toronto, Toronto, Ontario, Canada.

Reduction of Iron Ore Particles in Beds: *A. E. El-Mehairy*, Research Metallurgical Engineer, and *W. O. Philbrook*, Professor of Metallurgical Engineering, Carnegie Institute of Technology, Pittsburgh, Pa.

Steelmaking by the HyL Direct Reduction Process: *R. Lawrence, Jr.*, Sales Manager, Iron and Steel Division, The M. W. Kellogg Co., New York, N. Y.

Tuesday, April 11

Sintering Session

9:00 am to 12:00 m — Pennsylvania West Room

Chairmen: *R. L. Wiegel*, Research Engineer, Graham Research Laboratory, Jones & Laughlin Steel Corp., Pittsburgh, Pa.
R. E. Hagen, Plant Superintendent, Saxonburg Plant, Edgar Thomson Works, U. S. Steel Corp., Braddock, Pa.

Generation and Treatment of Sinter Plant Dusts: *P. A. Young*, General Manager, Research and Development Division, Head Wrightson and Co., Ltd., Thornaby-On-Ties, England.

United States Steel Hot Ore Briquetting Process: *R. G. Thompson*, Chief, Raw Materials Engineering Division, *D. E. Rohaus*, Associate Technologist, and *J. R. Guseman*, Associate Technologist, Applied Research Laboratory, U. S. Steel Corp., Monroeville, Pa.

Blast Furnace Practice With 100 Per Cent Low-Grade Self-Fluxing Sinter: *Jean Michard*, Institut de Recherches de la Siderurgie, Maizires-les-Metz, Moselle, France, and *Guy Chanty*, Head, Metallurgical Department, De Wendel Co., France.

Ignition Conditions in Sintering: *J. M. Ridgion*, British Iron and Steel Research Association, Normanby, Middlesbrough, England.

Coke Session

9:00 am to 12:00 m — Pennsylvania East Room

Chairmen: *H. E. Harris*, Assistant Manager, Research Laboratory, Eastern Gas and Fuel Associates, Boston, Mass.
J. G. Pittinger, Superintendent, Coke Plant, Ford Motor Co., Dearborn, Mich.

Tuesday, April 11, Continued

Coke Oven Battery Innovations and Coal and Coke Preparation Facilities of the Coking Plant Kattwyk of the Hamburger Gaswerke, G.m.b.H.: *Georg Düwel*, Director, Hamburger Gaswerke, G.m.b.H., Hamburg, Germany

Relation of Properties of Coke Produced by the BM-AGA and Industrial Methods: *D. E. Wolfson*, Chief, Coal Carbonization Section, *G. W. Birge*, Chemical Engineer, and *J. G. Walters*, Chemist, U. S. Bureau of Mines, Pittsburgh, Pa.

Reactivity, Size Distribution, and High-Temperature Strength of Coke and How They Are Affected by the Coking Process: *H. Echterhoff*, Chief Engineer, Carbonization Research, and *W. Peters*, Section Manager, Processing and Technology Department, Bergbau-Forschung G.m.b.H., Essen-Kray, Germany, and *K. G. Beck*, Chief, Coke Department, Steinkohlenbergbauvereins, Essen, Germany.

A Study of Combustion Conditions During Reversal with Blast Furnace Gas Underfiring: *A. M. Cameron*, Technical Assistant, Coke Plant, and *G. W. Sagle*, Coke Plant Engineer, The Algoma Steel Corp., Ltd., Sault Ste. Marie, Ontario, Canada.

Computer Application Session

9:00 am to 12:00 m — Penn Center Room

Chairmen: *S. A. Bell*, Senior Research Engineer, Research and Technology, Armco Steel Corp., Middletown, Ohio.
J. R. Lowe, Superintendent, Blast Furnaces, Pittsburgh Works, Jones & Laughlin Steel Corp., Pittsburgh, Pa.

What Are Computers?: *D. C. McCune*, Senior Statistician, and *J. C. Buker*, Research Engineer, Jones & Laughlin Steel Corp., Pittsburgh, Pa.

Mathematical Method for Analyzing and Predicting Changes in Blast Furnace Operations: *A. L. Hodge*, Associate Manager, Gas Processes Development, and *E. R. Wyczalek*, Development Engineer, Linde Company, Division of Union Carbide Corp., Newark, N. J.

Computer Applications in the Blast Furnace Area: *D. S. Macoy*, Staff Supervisor, Computer Programming, Gary Steel Works, U. S. Steel Corp., Gary, Ind.

Annual Luncheon and Business Meeting, Blast Furnace, Coke Oven, and Raw Materials Committee

Tuesday, April 11

12:30 pm—Constitution and Independence Rooms
James Chisholm, Chairman

Everyone attending the Blast Furnace, Coke Oven, and Raw Materials Conference is invited to attend this luncheon and annual business meeting.
(Tickets $4.00, tips and tax included.)

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Tuesday, April 11, Continued

Joint Session

2:00 to 5:00 pm — Pennsylvania West and East Rooms

Chairmen: *J. R. Dietz,* Supervisor, Blast Furnace and Coke Oven Research, National Steel Corp., Weirton, W. Va.
James Chisholm, Superintendent, Central Furnaces and Docks, American Steel and Wire Division, U. S. Steel Corp., Cleveland, Ohio.

Iron Ore—The Big Picture: *E. H. Rose,* Chief Beneficiation Engineer, Koppers Co., Inc., Pittsburgh, Pa.

Application of Centralized Control to a Combined Mine and Coking Plant (Includes Motion Picture, "The Murton Coking Plant"): *M. D. Edington,* Carbonization Director, National Coal Board, Gateshead, County Durham, England

Panel Discussion: Carbonaceous Fuel Additives to the Blast Furnace Hot Blast:
Moderator: *D. H. Regelin,* Assistant Chairman, Operating Committee, Iron Production, U. S. Steel Corp., Pittsburgh, Pa.

Panel:

Joel Ramirez, Blast Furnace Superintendent, Altos Hornos de Mexico, S. A., Monclova, Coah., Mexico.

J. W. Carlson, Superintendent, Blast Furnace Department, Colorado Fuel and Iron Corp., Pueblo, Colo.

S. G. Anderson, Division Superintendent, Iron Production, Lone Star Steel Co., Lone Star, Texas.

E. R. Dean, Assistant General Superintendent, Coal and Iron Division, Pittsburgh Coke and Chemical Co., Pittsburgh, Pa.

H. C. Taylor, Superintendent, Blast Furnaces and Coke Plant, Dominion Foundries and Steel, Ltd., Hamilton, Ontario, Canada.

R. H. White, Division Superintendent, Blast Furnaces, Coke and Chemical Works, Fairless Works, U. S. Steel Corp., Fairless Hills, Pa.

W. M. Kreglow, Jr., Technical Assistant to Vice President, Bethlehem Steel Co., Bethlehem, Pa.

Past Registrants of the Blast Furnace, Coke Oven and Raw Materials Conference, AIME

You are entitled to purchase, at this time and at the special rate, the following available volumes of the Proceedings of the Blast Furnace, Coke Oven, and Raw Materials Conferences at $7.00 per volume ($10.00 to nonregistrants).

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FIRST CONFERENCE ON

MANAGEMENT OF MATERIALS RESEARCH

Sponsored by The Metallurgical Society,
American Institute of Mining,
Metallurgical, and Petroleum Engineers

Arden House, Harriman, New York • May 17-19, 1961

WEDNESDAY, MAY 17

1:30 pm **Opening Session**

Introduction and Statement of Objectives:
M. W. Lightner, U. S. Steel Corp., and *W. R. Hibbard, Jr.*, General Electric Co .

Organization and Staffing of Industrial Research:
J. H. Hollomon, General Electric Co.

Problems in the Management of Materials Research:
J. H. Jackson, Battelle Memorial Institute.

Case History—Industrial Chemicals A (Role of Manager-Scientist):
Charles Orth, Harvard University.

8:00 pm **Evening Session**

Identification of Problems in Research Management—Role of the Scientist and the Manager:
L. W. Steele, General Electric Co.

THURSDAY, MAY 18

9:00 am **Case History Clinic**

(Each of three case histories will be presented twice, thus enabling registrants to attend any two of the three.)

1. Houston Corporation (Staffing and Recruiting):
   A. Kendall, Harvard University.
2. Hastings Electronics (Appraisal of research projects):
   Albert Rubenstein, Northwestern University.
3. Haig Chemical Co. (Communication and transition):
   Charles Orth, Harvard University.

THURSDAY, MAY 18, cont.

2:00 pm **Lectures**

Fundamental Values of the Scientist:
Herbert Shepard, Case Institute of Technology.

Fundamental Values of the Manager:
Chris Argyris, Yale University.

8:00 pm **Discussion Period**

(To be centered around lectures presented during afternoon session.)

FRIDAY, MAY 19

9:00 am **Workshops**

Professors Orth, Kendall, Rubenstein, Shepard, and Argyris will each lead a workshop, to which roughly one-fifth of the registrants will be assigned. General questions to be discussed are the following:

1. What are the teachings of the Conference—both in general and as they pertain to the individual registrant?
2. What can be learned about such key areas as patents, publications, program balance, recruiting, measurement and appraisal, research financing, organization, and planning, communications, financing, etc.?
3. What topics should be covered in succeeding conferences, and which techniques are most valuable?

From each workshop group will come a statement of principles of the conference as well as recommendations for future conference planning.

WORLD'S RECORD

IN BASIC OXYGEN STEELMAKING ESTABLISHED BY HARBISON-WALKER LINING

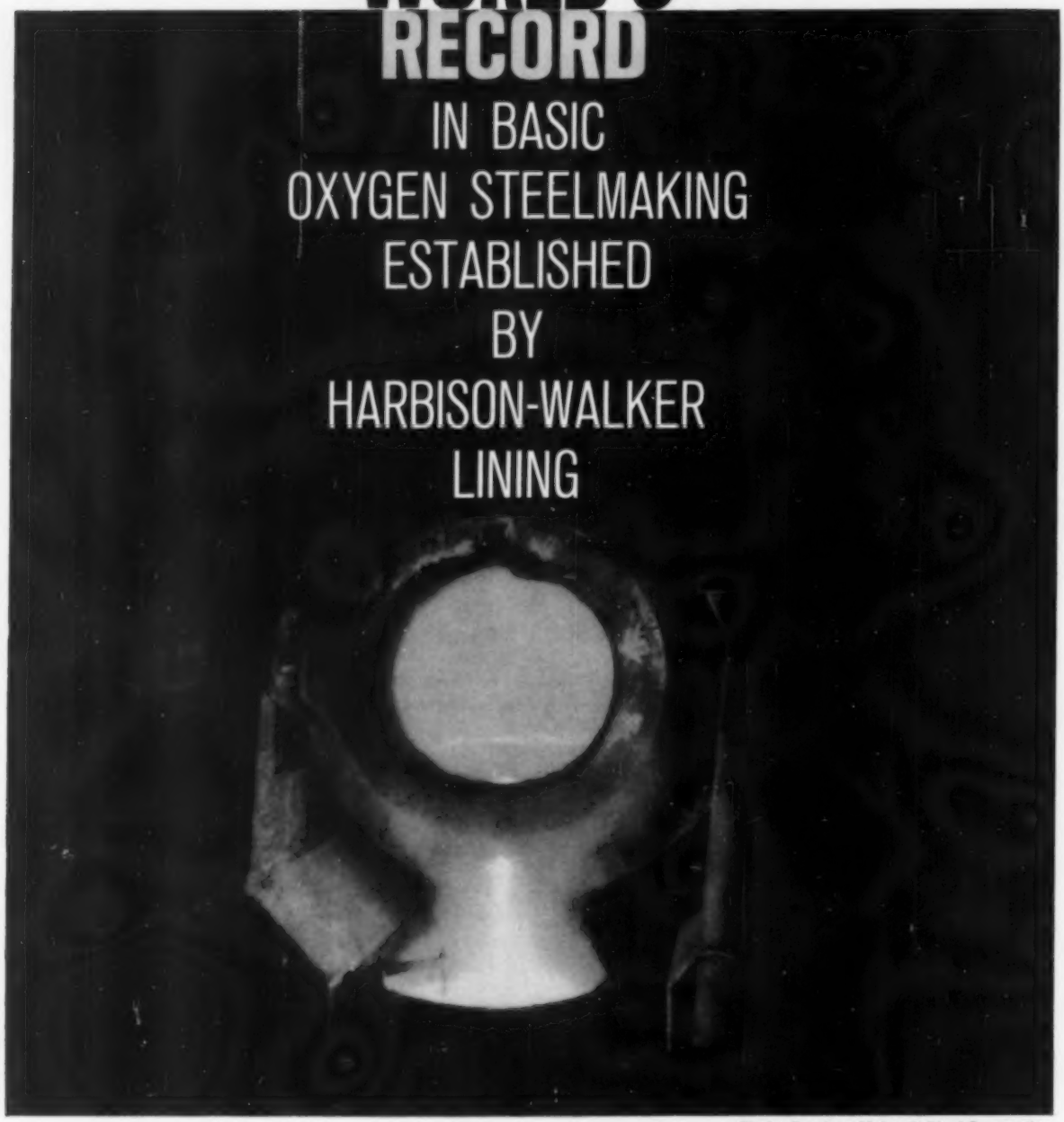

Photo: Courtesy McLouth Steel Corporation

A record number of tons of steel produced during a single furnace campaign has been achieved on a Harbison-Walker OXILINE H basic oxygen furnace lining. The campaign of 292 heats with negligible maintenance produced 31,405.05 net tons of steel.

Harbison-Walker produced the first tar-bonded basic brick in the United States . . . has been the leader in the field since the introduction of the basic oxygen process in this country . . . has developed and supplied linings for all furnaces in existence on the North American continent. In fact, more tons of steel have been produced on H-W OXILINE linings than on all other brands combined. HW 61-5

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PRESSURE VESSELS FOR SPACE, AEROSPACE, AND HYDROSPACE
A Symposium

Each year the Titanium Committee of the Institute of Metals Division presents a symposium on some aspect of technology pertinent to titanium and its application. As titanium becomes less and less one of the newer metals and more of a tonnage-type, structural metal, it has become desirable to give greater consideration to the relationship of titanium to alternative materials. At the 1959 symposium in Chicago, titanium vs steel was debated, with teams of speakers: one presenting the case for titanium, the other for steel. Debates were conducted on the general case, airframes, jet engines, pressure vessels, solid-fuel motor cases, and chemical and marine applications.

At the recent titanium symposium at the Fall Meeting of The Metallurgical Society in Philadelphia, a different approach was taken. The selection of materials is not made by debate, with popular voting to decide the choice. Instead, one man, or a group of men, with the responsibility for decision, looks at the various aspects of the problem, makes a decision on which material, composition, design, and processing method best fits the particular application. In keeping with this real-life situation, the 1960 Symposium presented the question of selecting titanium or an alternative material with a single speaker giving the balanced view of the pros and cons of titanium in the application, and the circumstances under which titanium would be selected in preference to competitive materials.

Pressure vessels are, perhaps, the most difficult and demanding of all structural applications for high-strength materials. The design criteria very often is based on whether or not the failure is subject to brittle fracture. Accordingly, the first paper in the symposium was *Evaluating Fracture Toughness*, by W. S. Pellini and J. E. Srawley, Metallurgy Div., U.S. Naval Research Laboratories. This was followed by *Pressure Vessels for Space*, by V. W. Cooke and R. C. Powell, of Pratt and Whitney Aircraft, East Hartford, Conn. This paper considered the materials and fabrication aspects of the pressure vessel problem, and described some of the significant work Pratt and Whitney has done on the titanium solid-fuel motor case. The third paper was *Structural Significance of Ductility*, by Professor George Gerard, of the New York University. This paper concerned the pressure vessel problem from the viewpoint of the designer, and may be considered complementary to the Pellini-Srawley paper. The last paper in the symposium was *Titanium Alloys for Hydrospace Vehicles*, by George Sorkin, Bureau of Ships, and Abner Willner of David Taylor Model Basin. This paper presented information on the status of a Navy program on titanium in deep-diving submarine hulls.

Summaries of the four papers are presented in the following pages. It is believed that the discussions concerning titanium in pressure vessels will be valuable in consideration of other materials as well, and that the selection of materials for pressure vessels thereby will be facilitated.

R. I. Jaffee, Battelle Memorial Institute

I. Evaluating Fracture Toughness

by W. S. Pellini and J. E. Srawley,

U.S. Naval Research Laboratory

In the design of pressure vessels for hydrospace, aerospace, or orbital space, the common objective is the attainment of minimum structural weight. The conventional criteria for evaluating the structural efficiencies of materials for pressure vessels involve strength-density ratios. The tensile yield strength index applies to the case of internally pressurized structures of the aerospace and space vehicles; however, for the externally pressurized structures of submarine hulls, the proper index is the compressive yield strength-density ratio. In this case, tensile stresses are important only for locations involving changes in geometry.

The purpose of this presentation is to describe the general status of the materials selection and design criteria for pressure vessels of the subject classes, as related to questions of fracture toughness.

Submarines may be constructed using both single and double hull features, and may be either internally or externally stiffened, depending upon design requirements. Fracture toughness requirements differ greatly, depending on the mission of the submarine. In the case of experimental or research vehicles, the primary requirement is the resistance to fracture propagation at regions of tensile stresses which ordinarily involve points of intersection. In the case of combat submarines, the fracture toughness requirement is much higher because the structure must be capable of withstanding underwater explosive attack. For service conditions involving explosion loading, a high order of fracture toughness is required to prevent failure of the hull at points of intersection and connection.

The selection of materials was based on results of explosion tests of plate ranging in size from 14 x 14 in. for ¾ and 1 in. thick plates to 30 x 30 in. for 3 in. thick plates. The tests involve placing a highly-brittle weld bead on the plate surface and explosion loading to force the propagation of a fracture from the initial crack developed in the brittle weld bead.

It was found that correlation between the explosion test and the Charpy V test methods depends upon the strength level of the steel, as illustrated in Fig. 1. The principal difference is that the transition temperature range of the explosion test corresponds to a higher part of the Charpy V transition temperature interval for the quenched and tempered steel, as compared to that of the mild steel. If such adjustments are made, the Charpy V curve provides excellent predictions of explosion test performance for any selected temperature. While Charpy V data may be used for preliminary screening, the proof test of the adequacy of the material is a full-thickness, crack-starter explosion bulge test conducted at 30°F and 0°F.

It should be noted that the plate fracture path is only one of the potential paths of fracture in weldments. Brittle fracture paths may also be developed in the weld and the heat-affected zone. Thus, a plate material which has demonstrated adequate fracture toughness in crack starter tests must be further evaluated as a weldment. This property can also be evaluated with both explosive and Charpy V tests. However, limitations of the Charpy V method should be recognized. In large measure, the importance of the test evolves from the lack of significantly better competing methods; in contrast to sheet metal material, tests of heavy plates or forgings in full thickness are not generally feasible.

Service conditions

The exact relationship of service conditions to fracture toughness requirements is poorly understood even at this date. The National Bureau of Standards (NBS) has established that, irrespective of the unavoidable variations in weld properties and heat affected zones, the common denominator of ship structure is the notch ductility properties of the material.[1]

Points of stress concentrations, such as hatch corners, were found to involve high stress gradients, resulting in localized yielding at low levels of nominal stress. Welds located at such sharp corner positions provided a high statistical probability for the presence of crack-like flaws. The early classical work of Robertson[2] and later of Feeley[3] provided documentation for the validity of the concepts. Their studies were aimed at establishing the interrelation of temperature and stress of the propagation of brittle fractures in mild steels. Robertson-type tests clearly demonstrated the requirement of localized plastic flow for the initiation of brittle fractures from relatively small, crack-like defects located in a structure that is otherwise loaded to low nominal stress levels. The effect of temperature was shown to be extremely critical, in fact, for practical purposes the transition may be quoted as a single temperature rather than as a range of temperatures.

A large body of correlation data firmly defined the significance of these transition temperatures with respect to normal (non-plastic loading) service conditions[4]. Above the nil ductility transition (NDT) temperature, the fracture toughness of mild and medium strength steels was indicated to be too high for fracture initiation under normal conditions. Above the Robertson or fracture transition for elastic loading (FTE) temperature, the fracture toughness was indicated to be too high for fracture continuation under conditions of elastic loading. In other words, a fracture started in a more brittle steel plate or as the result of plastic loading would come to a stop on entering an elastically-loaded plate of above the FTE or Robertson temperature characteristics. A crack-stopping test of this type conducted by Mosborg[5] clearly proved this point. For conditions of service entailing gross plastic deformation, the fracture toughness requirement must be placed at the highest possible level, i.e., full shear fracture or FTP performance.

On the basis of this evidence, Naval Research Laboratory (NRL) investigators developed new concepts[6] of increasing fracture toughness requirements for three generalized classes of service:

1) **General Case:** Service involving relatively low nominal elastic loads. The fracture toughness requirement was defined as sufficient to allow for the development of highly localized yield point loading at positions involving the presence of relatively small flaws. For this case the NDT transition was deemed to govern;

2) **Accident Case:** Forced initiation of a fracture by plastic deformation loading of isolated areas of the structure. This case also relates to conditions involving the presence of very large flaws and high elastic load stresses. The fracture toughness requirement was defined as related to the Robertson transition or the FTE transition; and

3) **Military Case:** Specifically related to submarine service involving loading of large areas to levels of gross plastic deformation. The fracture toughness requirement was defined as equivalent to the development of full shear fractures of high propagation resistance, FTP in the explosion test.

Evaluating new materials

The final demonstration of fracture toughness suitability for future materials will entail underwater explosion tests of full-scale submarine hull sections. Before such construction is attempted, explosion loading fracture toughness evaluations will be made of structural test samples and of butt-welded plates. Prior to these tests, the plate material will be evaluated by explosion crack starter tests, and any failure would eliminate that material from consideration for welding trials. Preliminary screening of the materials will be performed with Charpy V tests.

Correlation of Charpy self-energy features and explosion test fracture toughness is being developed by NRL for steels having yield strengths as high as 175,000 psi. Among the problems are that steels of strength levels in excess of 90,000 psi yield strength decrease in fracture toughness of full shear (FTP) fractures, and that experience with correlations of Charpy V, or any other laboratory fracture toughness index for titanium or aluminum, is very limited. Preliminary investigations to establish correlations for various titanium alloys will be reported in a companion paper in this series, *Titanium Alloys for Hydrospace Vehicles.*

Thin walled vehicles

For thin walled vehicles, the relative structural weight is of prime importance. Ratios of allowable stress to density range from perhaps twice as high as for the current submarines to values as high as the designer's fancy may lead him—a popular target for rocket casings at present is 1-million psi per lb per cu in.

The temperature dependence of fracture behavior does not serve the same purpose for these thinner materials. Their fracture behavior certainly is temperature dependent, but temperature dependence alone is not sufficiently discriminating; therefore, a different approach must be taken.

There is considerable diversity of opinion concerning the evaluation of fracture toughness of these materials; however, there is apparently one approach which has found widespread acceptance, and is our main concern here. This approach involves the direct determination of the effect of crack-like flaws on fracture strength of materials by tension testing of specimens provided with notches or slots which are sharp enough to simulate such flaws. Stress analysis methods then provide a means of making use of this data in design against fracture, subject to certain important limitations imposed by the complexity of fracturing phenomena. In general, this technique is similar to Mosborg's crack-arrest type test. The complexity of fracture toughness evaluations is well indicated in the remaining references listed at the end of this paper.[7-28]

Conclusions

The proof of the pudding is in the eating, and the ultimate evaluation of materials for these applications depends on destructive tests of full-scale structures and parts of structures, and even more on proof tests and service performance, since only a very limited number of full-scale tests can be afforded. Very few variations in the factors of design, construction methods, and materials can be evaluated by this means for obvious reasons. Somewhat more in this direction can be done by destructive testing of sub-scale model structures, as an essential intermediate step. As one of the bases for selection of materials for this intermediate stage of evaluation, tests are needed which eliminate complicating factors of design and construction, and concentrate on the resistance to fracturing of the material in isolation.

In all practical examples of fracture failure, other than those due to crass error in design or execution, or to accidental overloading involving deformation, the fracture originates at some defect. Fracture testing is, therefore, essentially concerned with the tolerance of materials to sharp flaws or cracks. This is what constitutes fracture toughness.

The fracture toughness of many important engineering materials is very high when they are used at suitable temperatures. However, it drops rapidly with temperature in a range characteristic of the material. This severe temperature dependence is the basis of the successful methods for evaluating submarine hull steels and other structural steels in relatively thick sections and at medium strength levels. Attempts at direct measurement of fracture toughness of such materials have generally not been successful. Charpy V, drop weight, and explosion loading testing is the order for evaluating these materials.

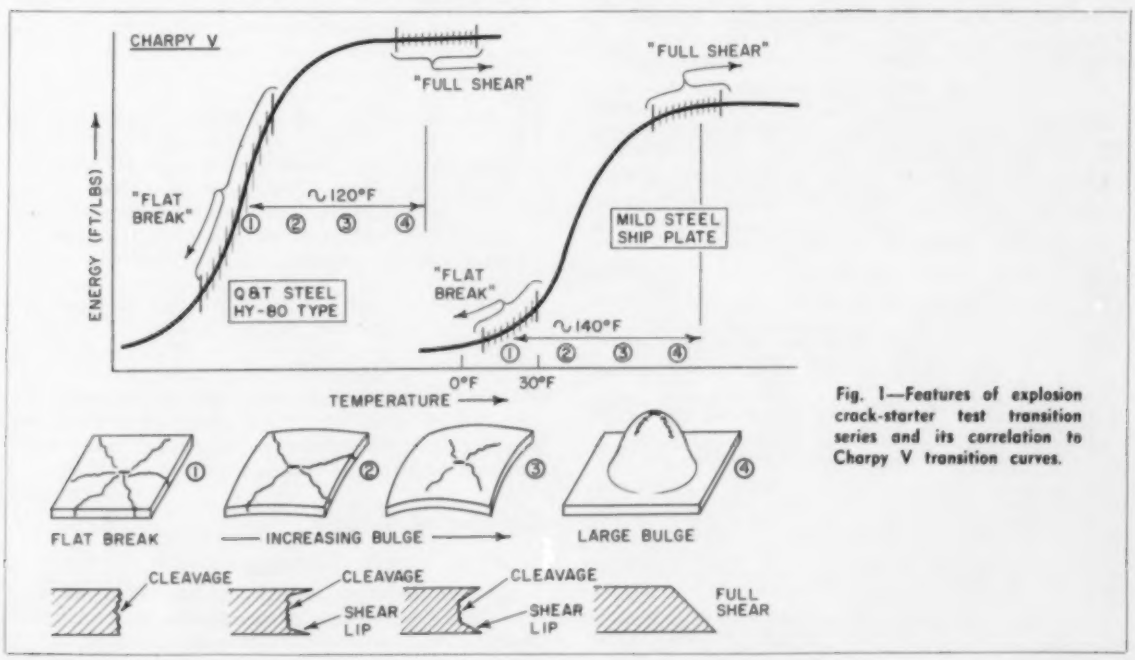

Fig. 1—Features of explosion crack-starter test transition series and its correlation to Charpy V transition curves.

High strength, thin-section materials can be evaluated by tensile tests of sharply slotted or notched specimens, which are adequately sensitive when the specimens are large enough in relation to the critical crack index of the material. The nominal net section stress (notch strength) of a standardized specimen serves satisfactorily for initial screening. More sophisticated interpretation in relation to the requirements of the application is provided by the methods of fracture mechanisms, but this has limitations which will be the subjects of research for some time to come.

For these materials, a transition temperature, such as the full shear temperature, is not an unambiguous criterion. On the other hand, many such materials are very sensitive to temperature, and under no circumstances should data be extrapolated from a higher to a lower temperature. Likewise, the fracture toughness depends on thickness, and data should not be extrapolated from a smaller to a greater thickness.

Fracture is by no means thoroughly understood. There are a variety of different views which deserve respect, but which have not been treated here. The purpose of this paper has been to give an account of the ideas and methods that appear to find the most widespread application. Naturally the account is colored by the ranges and limitations of the authors' backgrounds.

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II.

Materials for Space Pressure Vessels

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In considering materials for space pressure vessels, we must emphasize the major design requirements. Without going into detail, they can be listed in the order of decreasing importance as follows: high strength:weight ratio, ductility and fracture toughness, fabricability, corrosion resistance, and stability.

But there are a number of other factors, the importance of which depends greatly upon the particular application. For example, cost is more important in production military applications than it would be in research vehicles. High modulus of elasticity is a useful property. Low thermal conductivity might be quite desirable for cryogenic use. Lack of radiation resistance could be serious, depending upon the destination or path of the vehicle, and whether human beings are on board.

Current Materials

Steels

Medium-carbon low-alloy steels, such as SAE 4340, AMS 6434, and D6A, operate in solid-fueled ballistic missiles at yield strength levels of 185 to

200 ksi, with tensile elongations of 8 pct or more and good fracture toughness. They are readily fabricated, although heat treatment of large sizes is a problem. Properly heat-treated, they should be stable throughout their life period; however, they do not have adequate corrosion resistance and must be appropriately protected both inside and out.

The 5-pct Cr hot-work type die steels, such as H-11, are in use on at least one IRBM at the 200 to 220 ksi yield strength level. This steel is readily fabricable, and its hardenability, which is higher than low-alloy types, permits air hardening of heavy sections with minimized distortion. In spite of lower fracture toughness, H-11 pressure vessels properly processed have shown burst strengths of 300 ksi with consistency. Naturally, some refinements in processing are utilized in order to gain reliability at this strength level, but the production method employed is not unconventional. H-11 steel does not have adequate corrosion resistance, in spite of its higher chromium content; so, it must be protected against corrosive environments.

The martensitic 12 pct Cr stainless steels do not appear to be in extensive use in any of the missile programs, although they have been widely used for pressurized cases in jet engines at yield strength levels up to 150 ksi.

Austentitic stainless steels, such as AISI Type 301, are in successful use on one of our earlier large ICBM's fabricated in a cold-worked condition at a yield strength of at least 155 ksi and tensile elongation of 8 pct or more. This material is serving as a container for liquid oxygen, which means its operating temperature must be approx −320°F or colder. In many cases, the walls of such vessels are so thin that they must be pressurized in order to maintain sufficient rigidity for handling. One advantage of the cold-worked nickel-chromium austenitic steels is their excellent corrosion resistance.

Some of the highest strength hardenable stainless steels now being tried to a certain extent are the 17-7PH or AM 350-357 types, which are capable of yield strengths above 200 ksi, although ductility becomes quite marginal. These steels have a rather unique advantage of being fabricable in a solution heat-treated condition and hardened by relatively low temperature cold treatment and aging, at 850° to 900°F. These alloys have good overall corrosion resistance, but are subject to stress-corrosion when in the fully hardened condition.

Another group of iron-base alloys, under development by the International Nickel Co., shows promise of high strength levels combined with ease of fabrication. These steels contain 20-25 pct Ni, plus Ti or Al, and are hardened by solution heat treating at 1500°F, refrigerating, and aging at 800-950°F. Higher strengths are achieved by cold reduction prior to aging. Yield strengths of over 260,000 psi with 6 pct minimum elongation and high reduction of area (25-40 pct) are obtainable with present analyses, and cold worked material offers the possibility of yield strengths in excess of 300,000 psi, with acceptable ductility. These steels have several advantages:

1) they are capable of attaining high strength levels by relatively simple, low temperature processing;

2) they show promise of excellent toughness, with notch:strength ratios in excess of 1:1, even at yield strength levels approaching 300,000 psi; and

3) they should show good cryogenic properties, at least at intermediate temperature levels (to −175°F).

On the debit side, the 20-25 pct nickel steels will have to be controlled very closely in composition in order to attain uniform properties, and their corrosion resistance offers no significant improvement over low-alloy steels, so that a corrosion-resistant coating will be necessary.

Aluminum alloys

Aluminum alloys seem to have had the greatest preference for pressure vessel use, at least for liquid fuel storage, and are widely used in more recent vehicles. Alloys such as 5086 have been employed at yield strengths of approx 45,000 psi, although strength alloys such as 2014 and 7178-T6, are being tried. Aluminum alloys apparently are satisfactory for liquid oxygen storage. Reference to Fig. 1 shows some of the strength:weight ratios of aluminum alloys compared with those of other materials in current use.

Titanium alloys

Titanium alloys have had a very limited use, mostly as small spherical containers for helium storage. The C-120AV (6Al-4V) alloy has been used for this, and is capable of 120 ksi room temperature yield strength as annealed, or 155 ksi in a solution heat treated and aged condition. This material has been the *work-horse* titanium alloy of the jet engine industry. It has good forgeability and is readily weldable.

Future materials

What then, are the possibilities for advanced materials for the future? Using production techniques and equipment now available, it is not difficult to foresee use of low alloy, hot work die, or precipitation hardening steels at a yield strength level up to 270 ksi. Ductilities and fracture toughness will be at a minimum, but if proper design and fabrication are employed, this strength level is within present capability. If we make use of exotic fabrication practices such as ausworking, i.e. deformation within the lower austenitic bay of the TTT diagram, we see a good possibility of yield strengths of at least 350 ksi and quite possibly 400 ksi, with tensile elongations still above 3 pct[2, 3].

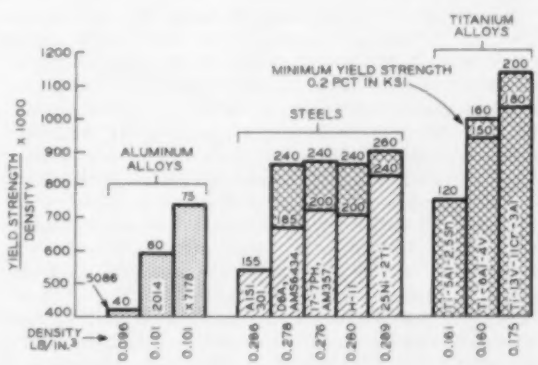

Fig. 1—Strength-weight comparison of various missile case materials currently available.

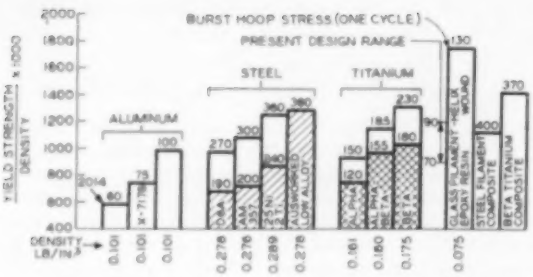

Fig. 2—Strength-weight comparison of pressure vessel materials projected to 1965.

Whether this type of processing is capable of producing structures with usable fracture toughness is the question. It is certainly a big question when the high side of the possible strength range is considered. Comparisons of strength levels of steels with various processing techniques are illustrated in Fig. 2. As a word of caution, here, ausworking is not currently a production process other than for wire or possibly strip and bar, and it is open to quite some speculation as to whether full-scale cases can be so constructed without being of a composite wrap-type design.

As far as aluminum alloys are concerned, it is conceded that yield strengths in the 90 to 100 ksi range are probably the best we can hope to gain, based on foreseeable processing, combining improved alloys with cold work, and age techniques. On a strength:density comparison, this is just enough to compete favorably with 6Al-4V titanium alloy at 155 ksi yield strength, as seen in Fig. 2, giving a ratio of 970,000. On this basis, it would appear that aluminum alloys will probably not give the ultimate goal in mechanical properties, particularly if a strength:density ratio of well over 1-million, or performance at temperatures much above 70°F, is required. We should not overlook their attractive features of relatively low cost, good corrosion resistance (particularly with some of the rather unstable liquid oxidizers), and easier fabricability.

Magnesium alloys do not appear to offer sufficient incentive on a yield strength:density basis to look attractive as pressure vessels, despite their value in airborne structures where rigidity is needed. The highest ratio obtainable for yield strengths of 35 ksi and density of 0.0475 lb per cu in. is only 740,000[4].

Alloys of beryllium look dubious for the future. The low density of beryllium is not enough, unless accompained by developments in the area of higher strength alloys. On a strength:weight basis alone, current Be-BeO alloys are not up to alloys of titanium. To date, it does not appear that the problem of higher strength plus adequate triaxial ductility will be solved quickly, although progress is being made. Costs, of course, are considerably higher than with any of the other metals previously discussed. Beryllium is very attractive, however, because of its low density, high modulus, and reasonably good corrosion resistance.

If we are to build space vessels with yield strength:density ratios exceeding 1,000,000, what are we to use? The best low-alloy steel processed to 250 ksi yield strength gives us about 900,000. If we can auswork such a steel as H-11 or equivalent to 325-350 ksi yield strength, this would give 1,150,000, at best. Looking to future possibilities of a yield strength of 360 ksi, the ratio becomes 1,300,000. This is getting into the same league with properties reported for resin bonded glass fibers, but it is postulating a production technique that we do not have at present, with reliability a moot point.

Taking a closer look at the titanium picture, we have previously noted that the C-120AV alpha-beta alloy can be processed today at 155 ksi yield strength, with some experimental data indicating that 160 ksi is possible by cold rolling and aging. At a density of 0.161 lb per cu in. this gives us a ratio of 1,000,000. However, considerable difficulty is anticipated in the flow-turning of the alpha-beta alloys due to their greater resistance to deformation as compared to the all-beta types. If we consider the all-beta alloy, B-120 VCA, at a yield strength of 180 ksi and density of 0.175 lb per cu in., we have 1,030,000. This is a realistic value, and the processing techniques and equipment are available for producing large pressure vessels at such a strength level.

Resin-bonded fiber glass structures have recently been announced as a production item for solid-fuel rocket casings on an advanced missile system. This type of material is reported to be well above current metals on a strength:density basis, and burst strength:density values as high as 1,800,000 have been cited, based on filament wound glass bonded with epoxy resin[3].

One experimental program has just been completed on an Army ballistic missile, culminating in the construction of three full-scale pressure vessels, one of which has been successfully pressure tested to destruction. This VCA vessel was deliberately controlled in its aging to a 180 ksi level. Its 0.2 pct biaxial yielding occurred at 200 ksi, giving an expected kick-up of 11 pct. Burst strength was about 8 pct higher than the uniaxial ultimate strength. Tensile elongations of the failed cylinder section ranged from 4 to 8 pct, depending somewhat upon orientation. There is good reason to believe that VCA is capable of significantly higher yield strengths than the 180 ksi employed in this vessel.

Conclusions

One conclusion of our program was that VCA alloy is capable of useful yield strengths as high as 200 ksi for use in pressure vessels, based on subscale testing. Further development of the alloy is continuing toward such a goal under a program sponsored by the Army.

Having taken a brief look at the strength levels that titanium alloys can develop as pressure vessels within the current state-of-the-art, we still are faced with certain disadvantages that should be weighed against those of other materials. For example, since VCA has a body centered cubic structure, it would not be expected to show good ductility at low temperatures. Work by the Naval Air Materials Center shows a marked lowering of ductility for annealed material below −100°F[5]. The aged material is even poorer in this regard as shown by some recent Battelle data[6]. This makes its use at temperatures below −100°F rather unlikely, at least in the high strength condition.

The C-120AV alloy, and to even a larger extent, the all-alpha A-110AT alloy would be most useful for low temperature applications. We must recall here that the low-alloy steels in the high strength

condition are not likely to have sufficient ductility for use with liquid nitrogen at −280°F or lower temperatures. Although the 3.5 pct Ni carburizing steel AMS 6260 in the annealed conditions shows excellent properties at −420°F[7], its yield strength: density ratio at that temperature is still only 685,000. The alloy A-110AT at 120 ksi yield strength would be a toss-up with an aluminum alloy of 75 ksi yield strength, at a strength:density ratio of 750,000. Obviously, we should stick with the 6Al-4V if possible, since it is capable of higher yield strengths than the A-110AT. The probable lower ductility and lack of toughness of 6Al-4V at −420°F would be against it, as compared with the 5Al-2.5Sn.

The titanium alloys have a very definite advantage over the steels, generally, as regards corrosion resistance, even surpassing aluminum alloys for most environments. They apparently can be used with gaseous fluorine up to 250°F, and in contact with liquid fluorine at −310°F. Exceptions would be their adverse reactions with the fuming nitric acids and possible reaction with liquid oxygen. Titanium alloys other than the commercially pure material can suffer from halide stress-corrosion above 500°F (as do austenitic stainless steels). This is more apt to result in processing problems than in end use difficulties, as far as present space vehicles go, but it could become a problem. If so, anodizing or some other form of protection would be required. Stress-corrosion could be a problem with any of our candidates for space vehicles, as long as we require use of materials in their highest strength condition.

We might summarize this picture, in a sense, as a challenge to the titanium industry. Reference to Fig. 2 again shows what we think are the possibilities. Steel is here today, and we expect it to go higher. Fiber glass-plastic composites are also here and have a tremendous growth potential, whether used in pressure vessels, boats, or rifle barrels. Titanium alloys certainly offer us attractive strength: weight ratios at present—the highest for monolithic metal cases. They offer excellent corrosion resistance and good possibilities for use with solid fuels, nearly all the liquid fuels, and most of the oxidants. Certain alloys, including commercially-pure titanium, will be very useful at cryogenic temperatures where the fiber glass composites are not yet in evidence. What we do to improve processing techniques may well determine whether titanium will be a major working material in space pressure vessels. The essence of the challenge is how fast the titanium industry (and the users) can step up to meet the competition of steel and fiber glass.

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III. Structural Significance of Ductility

by George Gerard, New York University

In ballistic and space vehicles, a major proportion of the airframe weight is designed from tension considerations. This marks a distinct structural trend from manned aircraft and other lifting-type vehicles in which tension considerations govern roughly only one-third of the airframe weight and compression and shear buckling considerations govern the other two-thirds. As a consequence, the selection of materials for aerospace vehicles has generally focussed attention upon the maximum tensile strength: weight potential that can be realized primarily in pressure vessel applications. It is important to note that the last statement implies that there is an essential difference between the strength of tension structures and the tensile strength of materials. This difference is intimately associated with the presence of stress concentrations in the structure—those that arise at structural discontinuities and which are determinate in character as well as those of an indeterminate nature that inevitably result from fabrication.

The relative importance of stress concentrations upon structural tensile strength depends strongly upon ductility. It is well recognized, in a qualitative manner, that the greater the ductility, the greater the reduction of the stress concentration from its elastic value. Thus, methods of quantitatively evaluating the structural significance of ductility become of paramount importance in the attempt to exploit successfully the attractive tensile strength: weight characteristics of high-strength sheet materials.

The rather loose connotation of the word ductility is perhaps indicative of the fact that, in the past, structural engineers did not require a precise description of this particular material property to design reliable tension structures. Apparently satisfactory was the commonly-accepted measure of ductility as the 2 in. gage length strain obtained after fracture of a structural tensile specimen of prescribed configuration. It is widely recognized, however, that such a measure of ductility is merely an acceptance test value that bears little significance to the ductility values pertinent to various structural applications.

Because of the fact that stress concentrations act as weak links in a structure, it appears that fracture strains associated with the localized region of the stress concentration may provide some meaningful estimate of the structural significance of ductility. Accordingly an exploratory program was initiated to measure fracture strains in very small gage lengths of the order of 0.01 in. on parallel sided tensile specimens and those containing a circular hole as a representative stress concentration.

A study of possible strain measurement techniques for the investigation of small gage length strains on low-ductility materials led to the selection of a test based upon photo-deposition of an accurately-ruled grid on the polished surface of the specimen. During the course of the test, the displaced grid lines are photographed on glass plates, and the relative displacements of the individual lines, which determine local strains, are measured with a special precision photo-micrometer.

One of the significant results of these tests is that strain does not increase up to the point of fracture, but instead reaches a maximum within the fracture zone contained between the fracture locations on the top and bottom surfaces. This observation is probably a result of the very small 0.01 in. gage length grid used in these experiments. It is apparent that, if 0.05 in. gage length grid had been used, the strains would appear to increase up to the point of fracture.

Another observation is that the maximum local strain at the edge of a stress concentration for the concentric-hole specimen is on the same order of magnitude as the maximum local strain observed for the parallel-sided specimen.

In order to investigate the influence of geometry upon fracture strains in a preliminary manner, the dimensions of all specimens were held constant, except for the cross section, which was varied both in width and thickness. For the specimens without stress concentration, the local strains in the region of fracture were obtained for each specimen along several lines parallel to the longitudinal axis of the specimens and evenly distributed over the specimen width. For the specimen with the stress concentration, the strain distribution was measured on both sides of the hole. Results indicated that the strain distribution remained the same, but the magnitude varied somewhat over the width of each specimen as well as from specimen to specimen.

As a result of this exploratory program, the following tentative conclusions can be drawn from the tests on the Ti-7Al-4Mo titanium alloy, utilizing the 0.01-in. gage length grid:

1) A clearly definable maximum strain is observed on the surface of the parallel-sided tension specimen, provided that the grid gage length is on the order of 1/5 of the specimen thickness. The maximum strain varies somewhat with the position across the width and is influenced by specimen geometry; and

2) The maximum strain in the stress concentration specimens observed at the edge of the hole is directly comparable to that obtained on a parallel-sided specimen of equivalent width-thickness ratio.

Analysis of stress concentration

These experimental results established that very small gage length strains are involved in the fracture of stress-concentration specimens; hence, it is pertinent to consider the behavior of stress concentrations from an analytical viewpoint. In this manner, it is possible to establish relations among the factors that influence notch strength: elastic stress concentration, geometry, and ductility.

The reduction of an elastic stress concentration as the stress is increased into the plastic range has been analyzed by Stowell[1] and has been employed in the work of others.[2-4] It has been shown that, for cases where the net section stress is elastic—notch:unnotch strength ratio somewhat less than unity—a ductility ratio can be found which ranges between unity for a truly brittle material and approaches zero for a very ductile material. This ductility ratio, e, is the ratio of the brittle strain, e_b, to the ductile strain, e_f.

In addition to this effect for plastic stress concentrations, there is also an opposing effect of stress concentrations that causes strengthening.[5] Apparently as a result of the triaxial stress field existing in the vicinity of a severe notch, the net section strength of a highly-ductile material can be considerably higher than the ultimate tensile strength as measured on a smooth specimen of the same material. Similar results have also been obtained by other investigators.[6]

Structural design significance

Associated with the structural applications of materials are certain environmental and loading conditions that may significantly affect design performance. Among these factors may be included stress field, temperature, strain rate, stress concentrations, and size effects. In order to guard against inappropriate use of materials under certain combinations of these factors, metallurgists have utilized tests such as the Charpy, notched tensile, slow bend, and others to screen materials. In a structural design sense, these tests have been useful in the rather restrictive sense that they establish temperature conditions under which notch sensitivity is likely to become of importance. For example, the features incorporated in a Charpy V-notch test include a relatively high stress concentration, a rather severe stress field, and a relatively high strain rate at various test temperatures. Because of the severity of the test, it has proved to be effective in guarding against poor structural designs that ignore the presence of severe stress concentrations and fabrication flaws under low temperature conditions. This test, in a way, effectively isolates the metallurgical problem from the structural engineering problem, since in order for a material to pass the Charpy test it must have sufficient ductility to accommodate severe

stress concentrations. Upon passing this test, the structural designer is free to use the material with the hope that ductility will forgive all.

Recent attempts to use high-strength sheet materials in aerospace pressure vessels have resulted in the recognition that extreme care in design and fabrication is mandatory to achieve anything near the full strength-to-weight potentials of the sheet materials. As a consequence of this recognition, the notch tests used in the past, as well as those recently devised, may now be too severe for those cases in which the requisite attention has been given to design and fabrication. It would seem, for example, that notch sensitivity could be incorporated directly into the design process, if this property were evaluated in terms of the appropriate stress field, temperature, strain rate, size, and particularly in terms of the appropriate stress field, temperature, strain rate, size, and particularly in terms of stress concentrations representative of the structural application.

Ductility ratio

In order to indicate a possible approach for incorporating the results of stress concentration tests into the structural design process, it is necessary to evaluate and analyze the ductility ratio, e. It can be observed in Fig. 1 that by plotting the plastic stress concentration factor, k_p, vs the elastic stress concentration factor, k_e, a straight line of slope e should be obtained, since the ductility ratio may be expected to remain constant in the region where the net section stress is elastic. Values for k_e and k_p can be measured directly for each specimen; therefore, the ductility ratio can be found by utilizing graphs similar to those illustrated in Fig. 1.

The ductility ratio can be looked upon as a basic mechanical property that may provide a meaningful index of ductility in structural applications. It is noteworthy that the evaluation of the ductility ratio involves a straight-forward test procedure in which the strength of specimens containing stress concentrations is the only measured quality. Therefore, the ductility ratio is evaluated from these test data without requiring any direct measure of strain. As such, it represents a simple test procedure from which the effects of stress concentrations can be determined under the environmental conditions appropriate to the structural application. With a knowledge of the ductility ratio, plastic stress concentration effects can be incorporated into the design process.

Strength-to-weight considerations

In order to focus on strength-to-weight considerations related to aerospace pressure vessel design, we shall utilize the data presented in Fig. 1 to provide some estimate of the relation between the strength-to-weight and ductility ratios. For this purpose these data are summarized in Table I.

Table I. Relationship between the Strength-to-Weight and Ductility Ratios for Several Materials

Alloy	Ductility Ratio, e	UTS,[a] Ksi	UTS/Density, In. x 10^5
AMS 6434	0.023	240	0.86
4340	0.076	250	0.90
Ti-6Al-4V	0.049	170	1.06
Ti-5Al-3Cr-1Fe	0.093	190	1.16
Ti-13V-11Cr-3Al	0.170	195	1.11

[a] UTS = Ultimate tensile strength.

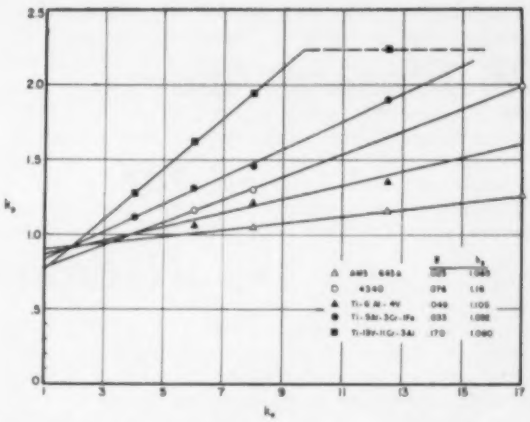

Fig. 1—Elastic stress concentration factor vs plastic stress concentration factor for various materials.

From the data in Table I, the following empirical relation was found between material strength-to-weight ratio and ductility ratio: UTS/density = $1.6 \times 10^5 e^{1/6}$. This relation fits the data within 10 pct limits; however, because of the small amount of test data upon which it is based, it must be regarded as tentative subject to further verification.

Since tension structures are characterized by stress concentrations of varying magnitudes, it appears useful to consider that the complex interaction between the strength and ductility of materials and the strength and ductility of structures can be idealized by assuming that the essential difference between material strength and structural strength is caused by stress concentrations[7]. Analysis has shown that most careful attention in design and fabrication to the minimization of stress concentrations is essential if the high strength-to-weight potential of materials is to be realized in tension structures. If a given level of stress concentration must be accepted, then there is an optimum strength-to-weight level for the material. Departures to either side of this level will result in a decrease in structural strength[8]. It is also known that for very sharp notches, high material strength-to-weight ratios lead to low structural strength-to-weight ratios.

Thus, ductility evaluated in the presence of stress concentrations can lead to the determination of a ductility ratio. This ratio can be considered a basic material property, and is of considerable help when used as a parameter in the design equations for pressure vessels.

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IV. Titanium Alloys for Hydrospace Vehicles

by George Sorkin, Bureau of Ships

and

Abner Willner, David Taylor Model Basin

As part of a long-range program to develop vehicles for hydrospace, the US Navy Department, Bureau of Ships has sponsored research in materials for use in construction of such vehicles; the titanium program is a portion of the overall project.

Owens and Sorkin at the 1960 AIME Annual Meeting pointed out the need for high yield strength-to-weight ratio materials for design of military submarines for extreme depths. Primary considerations were based on using current design concepts and only yield strength, density, and the modulus of elasticity of the materials were considered. However, the secondary characteristics of the alloys were found to play a critical part in material selection. These characteristics include: weldability, corrosion resistance, creep rate, isotropy; and resistance to brittle fracture.

In view of the attractive primary characteristics of titanium for deep diving submarines, the Bureau of Ships has been interested in examining a number of its secondary characteristics.

Alloy selection

The Bureau of Ships set up tentative mechanical and physical properties which were considered desirable in a titanium alloy for investigation as a submarine hull material. The characteristics were such as to obtain an alloy which would be competitive with steels having 200,000 psi yield strength. The requirements of the titanium alloys were: 1) yield strength— 120,000 psi min, 2) notch sensitivity —NDT −80°F and FTP 0°F, and 3) Creep—nil at room temperature at stresses approaching compressive yield strength. In addition, the alloys were required to have good weldability, formability, and endurance properties, and be obtainable in plates of up to 4 in. thickness.

The Titanium Alloy Selection group of the Department of Defense Titanium Alloy Sheet Rolling Panel cooperated in reviewing the alloys and selected the following for initial evaluation: unalloyed titanium, and 5Al-2.5 Sn, 6Al-4V, 8Al-2Cb-1Ta, 13V-11Cr-3Al, and 6Al-4Zr-1V titanium alloys.

The following ground rules were used by the Titanium Selection Group in screening the alloys proposed by the producers as meeting the Bureau of Ships criteria:

1) Production ingot (800 lb minimum) should have been produced and rolled to sheet or plate;
2) Composition should be disclosed;
3) 100 BHN avg sponge hardness to be used;
4) If not inherent in annealed material, the strength level is to be achieved by cold or warm working or heat treatment; and
5) All plates of a given composition to be produced from same ingot.

Ten groups of titanium plates were received from the four participating producers for this investigation. All groups except one consisted of four 1x20x20 in. plates, three plates designated for explosion crack starter tests, and one for drop weight and mechanical property studies. One group con-

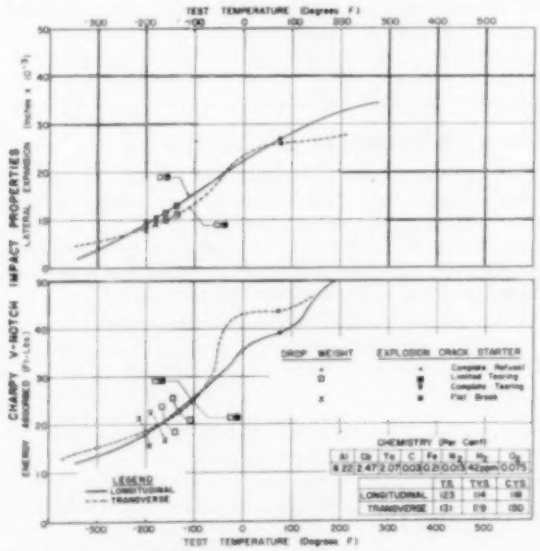

Fig. 1—Comparative Drop Weight and Explosion Crack Starter Data Fitted to the Charpy V-notch Curve.

sisted of a single plate, and this was used in the explosion crack starter test.

Testing

Tension, compression, and impact specimens were taken from the mid-thickness of test plates. Compression and impact properties were evaluated for both the longitudinal and transverse direction of plate rolling. Charpy V specimens were notched perpendicular to the surface of the plate. Drop weight and crack starter test specimens were full thickness of as-received plate; drop weight specimens were machined with the longitudinal direction in the width and were 1x3½x14-in. The explosion crack starter plates were 1x20x20-in. Brittle weld deposits in each case were welded perpendicular to the direction of rolling so that the machined notch would be parallel to the direction of rolling. All notches were machined to a depth of 0.07 in. from base plate.

Tension, compression, impact, and grain size evaluations employed standard ASTM test procedures. Naval Research Laboratory procedures were employed for drop weight and explosion crack starter tests. For both the drop weight and explosion crack starter tests, welding was performed automatically by utilizing metal arc inert-gas techniques.

Conclusions

Based on the limited data available, the following conclusions are tentatively drawn:

1) **Rate of loading:** The 8Al-2Cb-1Ta alloy had the least sensitivity to rates of loading, whereas the 5 Al-2.5 Sn alloy exhibited the greatest sensitivity. Since these alloys have essentially the same microstructure (acicular alpha) and similar compressive yield strengths for very low rates of loading, the differences in rate of loading sensitivity may be related to interstitials. It is apparent, however, that fabrication of these alloys will require slow loading rates in forming.

2) **Compressive vs tensile yield strength:** For a number of alloys the tensile yield strengths shown in Table I are higher for producer data than the tensile yield strengths determined by the authors. In these cases, as well as the significantly higher compressive vs tensile yield strengths shown for some of the alloys, the rate of loading is considered the significant factor.

3) **Ductile to Brittle Transition:** Titanium alloys exhibit ductile to brittle transition behavior with decreasing test temperatures. This is indicated by both lateral expansion and energy absorption levels in the Charpy V-notch tests. The appearance of fracture does not show the fibrous to cleaverage appearance that steel specimens exhibit under similar conditions.

4) **Energy Absorption:** A short horizontal energy absorption shelf has been observed in the Charpy V tests. With increasing temperatures up to 600°F, the highest test temperature used, the energy absorption level continues to rise rather than forming a plateau as has been found with steel. As noted for other high strength metals, the shelf level associated with full shearing is lower that those found for tougher lower strength metals.

5) **Prediction of Drop Weight or Explosion Crack Starter Plate Specimen Failure from Charpy V Curves:** The limited longitudinal and transverse Charpy V notch data indicated that a drop weight specimen or explosion crack starter plate will have a flat break where the corresponding Charpy V test shows energy values below 21 ft lb and the broken specimens exhibit a lateral expansion of 10 mils or less. Fig. 1 illustrates the comparative drop weight and explosion crack starter data fitted to the Charpy V-notch curve for 8Al-2Cb-1Ta which exhibited the best explosive loading performance of the alloys evaluated. The outstanding performance may be attributed to the all alpha nature and the low interstitial content (0.08 pct O, 0.01 pct N) of the alloy.

6) **Significance of grain size.** There appears to be a correlation between apparent grain size, as indicated by metallographic analysis using a solution of 2 pct HF and 4 pct HNO_3 in water as the etchant, and resistance to fracture under dynamic loading. The larger the apparent grain size, the lower the transition temperatures (FTE, FTP, and NDT). This relationship was found in all three of the tests used —Charpy V, drop weight, and explosion crack starter test.

Table I. Mechanical Properties of Titanium Alloys Producers' and DTMB Analysis

Alloy		Producers Properties				DTMB Check Results					
		Ultimate Strength, ksi	Tensile Yield Strength (0.2 pct), ksi	Pct El, (in 2 in.)	Pct RA	Ultimate Strength ksi	Tensile Yield (0.2 pct), ksi	Comp. Yield (0.2 pct), ksi	Pct El, (in 1 in.)	Pct RA	Compressive Modulus of Elasticity, x 10^6 psi
6Al-4V	L	142	131	11	NR	—	—	133	—	—	17.9
	T	136	120	11	NR	—	—	122	—	—	17.7
6Al-4V	L	—	—	—	—	—	—	122	—	—	17.1
	T	—	—	—	—	130	110	114	14	34	17.0
6Al-4V	L	141	136	14	32	—	—	—	—	—	—
	T	138	129	14	31	—	—	—	—	—	—
5Al-2.5Sn	L	135	123	11	NR	—	—	117	—	—	17.5
	T	144	132	11	NR	147	129	153	8	14.5	—
8Al-2Cb-1Ta	L	123	114	13.5	32.5	—	—	118	—	—	—
	T	131	119	13.0	19.0	—	—	130	—	—	—
6Al-4Zr-1V	L	145	138	17[a]	34.5	—	—	135	—	—	17.2
	T	144	136	17[a]	38.0	—	—	140	—	—	17.8
13V-11Cr-3Al	L	131	129	24.5[a]	25.4	—	—	124	—	—	14.8
	T	133	127	24.0[a]	25.2	129	121	120	9	38.4	14.4
13V-11Cr-3Al	L	136	135	12.5	25.4	—	—	120	—	—	14.4
	T	140	137	10.2	25.2	137	126	127	7	14.6	15.1
13V-11Cr-3Al	L	155	152	6.4	7.1	—	—	151	—	—	—
	T	NR	NR	NR	NR	—	—	—	—	—	—
Unalloyed	L	73	55	30.5[a]	51	—	—	51	—	—	16.3
	T	74	56	33.0[a]	51	70	49	49	22	51	16.8

[a] 1-in. gage.

EXTRUSION THEORY AND CALCULATIONS

This paper explains what a true extrusion theory should accomplish, indicates the present state of theoretical approaches, and compares the theoretical aspects to the current extrusion techniques.

by W. A. Backofen

Practical extrusion shares two important features with most other deformation-processing operations: it is extremely complex and its practice is far ahead of its theory. The latter is clearly a fortunate circumstance, considering the state of the theory.

As theory grows, there is reason for excitement among the devotees when it can first put into quantitative terms what is already known from experience, for this is an extremely important step. Unfortunately, this development in the theory may also interfere with its enthusiastic acceptance. The reason is simply that it adds so little new at this stage, yet it may still appear in such an involved form. Nonetheless, theory evolution goes on, and at the moment, in the specific case of extrusion it is growing fast.[1-5]

Most of the operations that depend upon deformation for shape changing and property control also share a number of common problem areas. Their relative importance and degree of interaction may change with the operation, but they can usually be identified, if only in a broad way. Five problem areas are indicated in just this way for the example of extrusion in Fig. 1:

Area 1 represents the deformation zone, generally regarded as the province of continuum mechanics and applied mathematics. There is concern here over the distribution of stress, displacements, and strain, the overall pressure requirements, and problems of die design as well;

Area 2 covers the interface between the elastically loaded tools (die, container, etc.) and the plastically deforming billet. There is strong interaction with other areas, especially 1. The concern is now with the difficult questions of heat transfer, friction, and lubrication under the unique conditions of plastic working, tool wear, and resulting surface;

Area 3 embraces the properties and characteristics of materials under conditions of processing. This is a critical, but rather neglected, metallurgical problem area, generally centered around strain hardening, recrystallization, fracture, etc. Very often the specific conditions of interest involve high temperatures and high strain rates, but these in turn may be only ill defined. Here is where the perennial problem of workability evaluation lies;

Area 4 is strongly metallurgical, based on structure and properties and how these are influenced by the deformation; and

Area 5 loosely represents the whole processing system and includes the primary deformation equipment plus auxiliary gear for heating, handling, etc. It clearly represents an area of much engineering activity.

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Requirements of a theory

It is relatively easy to say what a theory ought to do. In the first place, a theory ought to rest on an understanding of each problem area. Then, if it were to function ideally, it would assimilate basic property data and boundary conditions, consider the whole pattern of interactions, and eventually give out an optimum set of extrusion conditions for producing a certain product—whether this be a composite, a powder aggregate, or a strong and precisely shaped part. This is obviously a large order, and it could not possibly be filled today.

The metallurgist, for good reason, has often preferred to view such theory as a kind of analytical *black box* filled with a mechanism of differential equations, plasticity laws, tedious integrations, etc., and operated by specialists in mathematical plasticity. On this basis, then, an *ideal* theory might appear as in Fig. 2. Whatever lies inside the box, it ought to receive at the left data supplied largely by metallurgists and yield information about the items listed at the right. By a feed-back process both input and output would have to be adjusted to insure practically acceptable answers.

Although a complicated mechanism does in fact exist, it is not yet able to function in so intricate a way. Some of the reason is found in mathematical shortcomings, since theory develops with treatment of the relatively simple problems first. However, the mathematical solutions may also have limited value for still another reason, i.e. the lack of good data to present to the theory. The picture of stress distribution, as an example, is generally given in terms of material properties for special conditions of tool friction. This is done in the first place for mathematical convenience, but adapting the results for practical cases is made difficult because not many reliable data on properties and realistic boundary conditions are at hand. Microstructural variation in extruded pieces, as another example, might be better rationalized and even controlled with what is being learned about the strain, strain rate, and temperature history of extruding material; but good metallurgical background on recrys-

tallization kinetics under extrusion conditions is clearly needed to complement that information. The point of these remarks can be elaborated in more detail than space allows. Their main purpose is simply to emphasize that practical gains can also be expected from developing less qualitative and less subjective input data for the theory evolving today.

Methods of Calculation

Various methods of calculating extrusion force have been proposed from time to time, and these ought to be viewed apart from the more bona fide theory. Starting with data like that at the left in Fig. 2, they lead to values for pressure requirements but not along a route through the *theory box*. Their essential features can be illustrated with some discussion of a work balance that applies to all kinds of extrusion, and, in principle, to any other plastic-working operation as well. The terms, represented in Fig. 3, are the following:

W_a = total work actually required to extrude a billet of initial cross section, A, and length, l, and volume $V = A \cdot l$; this is the sum of:

W_h = the pure deformation work for homogeneous reduction of the volume from the initial to final cross section, indicated by the uniform compression of an initially thin, vertical and parallel-sided element in the billet;

W_i = the redundant or internal deformation work expended in straining not required for the pure shape change, indicated by shear added to the uniformly-reduced element; and

W_f = work done in overcoming frictional resistance at container and die face.

Both W_a and W_h are directly evaluated as shown by the few equations. W_h per unit volume is simply the area under a true stress-strain curve for the material and conditions of extrusion, whatever they are, up to strain $\epsilon = \ln (A_o/A_1)$ set by the reduction from A_o to A_1, or extrusion ratio $A_o:A_1$. To produce the last equation a shape-changing or deformation efficiency, η, is introduced, which is nothing but the fraction of all work done solely for the necessary shape change. This step collects into one quantity the much less clearly resolved work losses, W_f and W_i.

The development of explicit expressions for η, usually in terms of die profile, friction coefficient, and billet geometry, has, in effect, constituted much of the past work on calculation methods. Also needed for use of the last equation is the material's strain-hardening behavior under extrusion conditions. A usual, and often reasonable, assumption is illustrated in Fig. 4; the integral quantity, $\int \sigma d\epsilon$, can be approximated by the product of a deformation strength, or mean flow stress, and the over-all strain. Then the equation can be rewritten as shown with a quantity $b = \bar{\sigma}/\eta$, which is frequently termed the extrusion *constant*.

Various assumptions, reasonable and/or convenient, have been made at different times in the past in reaching a point where an equation is at hand. There can be little quarrel with the last equation as it stands; it is what is done next that determines its general usefulness, and here is where a basic weakness of calculation methods becomes apparent. Experiments are made and analysis brought into agreement with measurements by adjustment of as-yet unspecified parameters; the friction coefficient and deformation strength have often been so treated. The results may be practically useful, but clearly they must also be restricted to conditions like those of the experiments.

It sometimes happens that the measured pressure changes linearly with the logarithm of extrusion ratio, as indicated in Fig. 4. The slope of this line, if plotting is done with a scale of log-base 10, will be 2.3b where b is from the equation. Such direct meas-

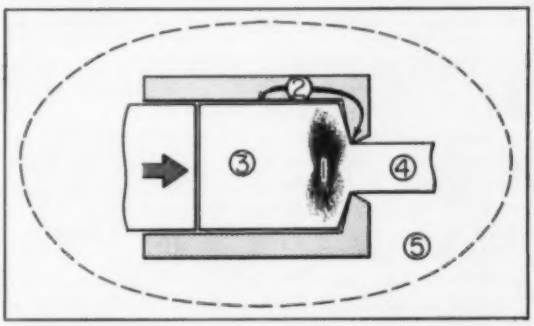


Fig. 1—Locations of various problem areas encountered in deformation processing operations.

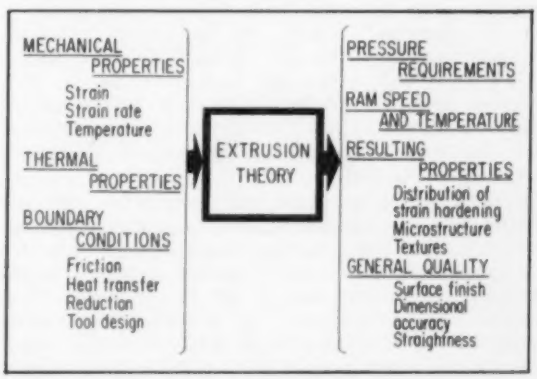


Fig. 2—Structure of an ideal extrusion theory.

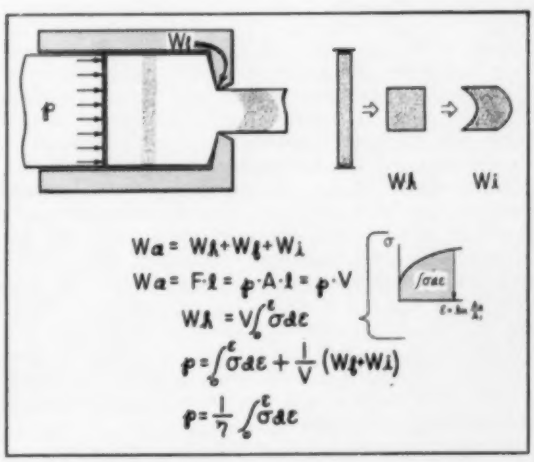


Fig. 3—Shape-changing work balance in extrusion.

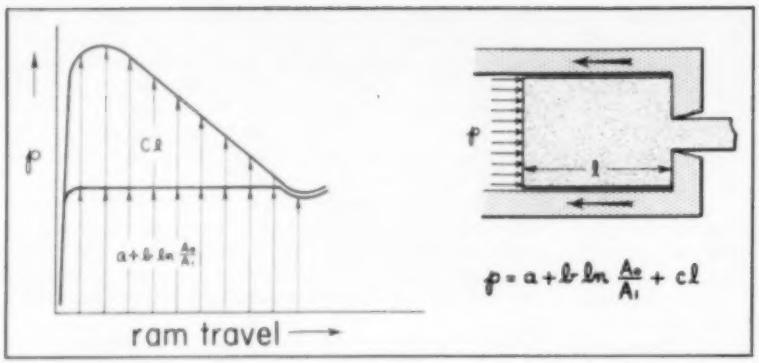


Fig. 5—Left, effect of sliding at billet-container interface in direct extrusion.

Fig. 4—Below, development of the usual logarithmic extrusion pressure formula.

urements of the extrusion *constant* are, of course, helpful in estimating pressure requirements for other closely-related operations.

A further complication in the problem comes from sliding through the container in direct extrusion. The discussion in this section up to now ought to be restricted to such cases as the indirect extrusion shown in Fig. 4 or the terminal stage of direct extrusion. Because of the sliding, a friction force, disposed as in Fig. 5, resists billet advance. This leads to a ram pressure, falling from an initial peak as the billet grows shorter and frictional drag decreases, unless a dropping billet temperature obscures such a trend. Therefore, a term containing the variable billet length, cl, must be added, and, for the most complete pressure formula noted in Fig. 5, a constant quantity *a* should also be included.

Many values for such *constants* are available. They have been measured experimentally for numerous specific situations, estimated by the calculation methods, and also evaluated in some instances by the more rigorous theory, following a path through the box of Fig. 2.[1, 6]

A brief mention of one more item is in order before turning to the next subject—the theory of limit analysis. In plastic working operations the pressure or force of most practical interest is generally the largest value that might be encountered. With methods of limit analysis, it is fairly easy to estimate this upper bound for a number of cases. As a byproduct, it is also possible to develop some insight into the resulting displacement and strain patterns.[9]

Extrusion theory

How a real theory ought to work has already been indicated. Its goals are ambitious, and even though it is becoming quite sophisticated today, there are goals that still lie a long distance ahead. Much elegant work has been done on the variation of stresses and displacements throughout an extruding mass. These mathematical investigations are generally self-contained, i.e. solutions are made in terms of unknown material properties and for carefully-specified boundary conditions. Despite obvious shortcomings, such work is valuable and represents most of the present-day theoretical pioneering in the deformation-processing field.[6] For this reason, it is worthwhile to discuss briefly a few examples of what has been learned with the theory. To do much more would require a large amount of time, energy, and interest.

Plane-Strain Extrusions: Detailed solutions have been made for extruding out of smooth (frictionless) containers under the condition of plane strain, e.g. extrusion of slab or sheet in which there is lengthening and thinning but no flow in the width direction. One of the simplest possible cases is illustrated in Fig. 6. The reduction is only 50 pct (H/h, or the extrusion ratio is 2), and the extruding material is regarded as plastic-rigid; it suffers no elastic strain, but yields sharply at a given stress level and flows further without work hardening. Dead metal regions are predicted, as shown, and the deformation zone is mapped out (in the upper half) with a slip-line field. It is important to realize that these slip lines are not at all like the lines that might be seen under the microscope on a polished and deformed sample. The only common feature of the two kinds of lines is their description as slip lines. The slip-line field in the present example is simply a fan of radial lines cut by circular arcs, each line being the trace of a surface of maximum shear stress and shear-strain rate. From known boundary conditions on stress, the pressure can be calculated within the zone. An example is given at the right. Here the axially-directed pressure over distance X-X through the zone from wall to wall is shown to vary from as much as $\sigma_y(1 + \pi/2)$ at one wall (where σ_y is the flow stress) down to 0 at the center line. However, everywhere to the left of the zone, in the as-yet undeformed material, pressure is constant over the

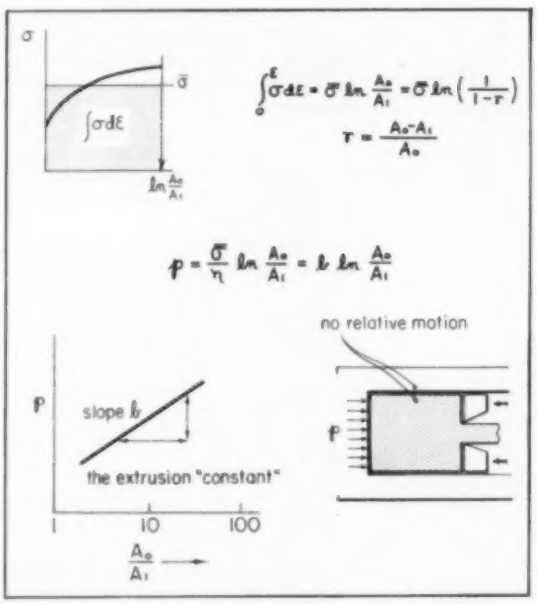


Fig. 6—Right, stress and distortion patters for 50-pct reduction by frictionless plane strain extrusion. Based on Hill.[6]

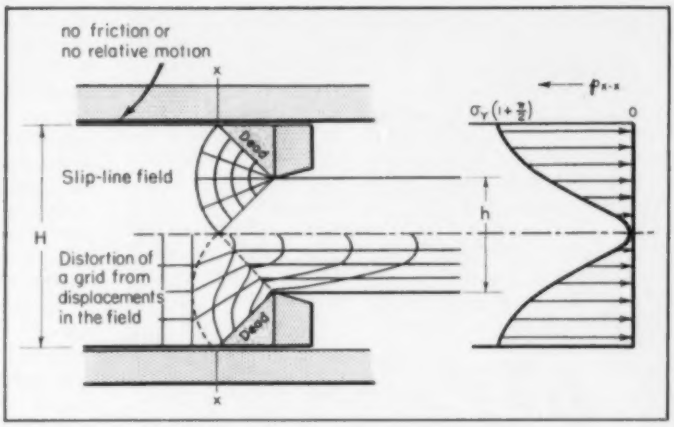


Fig. 7—Below, reduction dependence for frictionless plane strain conditions of extrusion pressure, piercing pressure, and deformation efficiency. Based on Hill.[6]

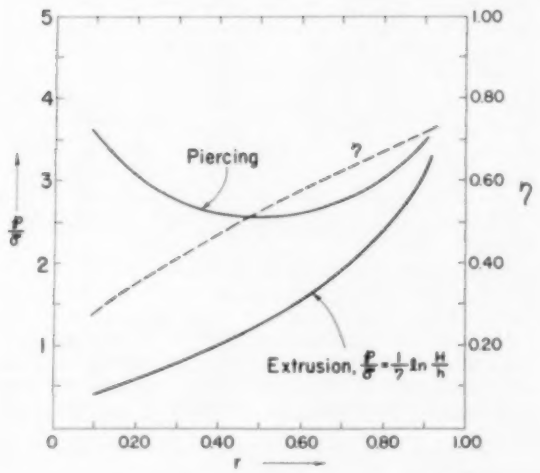
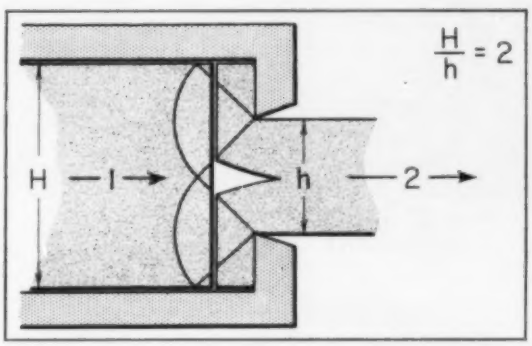


Fig. 8—Below right, formation of pipe during non steady-state extrusion.



thickness at a level: force/(billet cross sectional area).

The distortion of an initially square grid is also shown in the lower half of the figure. Clearly, the outer layers have been *held back*, and much internal shearing has gone on. Boundaries of the deformation zone are located with dashed lines in the background. The calculation can be made for the special problem at hand by knowing how incremental displacements vary along the slip lines of a field. A problem in composite extrusion is forming an initial interface between different billet materials that will lead to some required interface shape in the extruded length; the heavy distortion of vertical lines suggests how far from the final shape the initial interface might have to be. It is the fact of such basically non-uniform deformation that has been ignored so often in the past developments of calculation methods.

Since the example under discussion is frictionless, or indirect, nonuniform deformation determines the level of deformation efficiency. With the methods of slip-line field analysis, average ram pressure can be calculated in terms of σ, and reduction, which is equivalent to computing the deformation efficiency:

$$\eta = \frac{p}{\sigma_y \ln \frac{H}{h}}.$$

The predicted variation of η with r is shown in Fig. 7, where η is found to increase with r. Also presented there is the calculated ram pressure p as p/σ. These trends, plus the calculated grid-distortion patterns, have been well checked experimentally for the special conditions represented in the analysis. There has even been reasonable experimental agreement between such two-dimensional calculations and experiments on axial symmetric extrusions, e.g. cylindrical lead rods indirectly extruded through flat sharp-edged dies.[7] From the theoretical-experimental comparisons, it does seem possible to make good use of the findings from plane-strain studies in a number of more practical cases.

Another development could be fitted in very effectively at this point, although with space available there can be only a brief reference before moving on. This is the experimental plastic stress-strain analysis being applied in a variety of studies by Thomsen and coworkers at the University of California. The technique has been called *visioplasticity*, and the results it produces are proving extremely helpful in biulding stronger connections between extrusion theory and experiment.[8]

Non-steady State Extrusion: Eventually the unextruded billet becomes short enough that the plastic zone mapped out for steady-state conditions does not fit; it interacts with the ram face and is altered in shape. The steady state ends, and new problems appear. Pressure may fall and then rise sharply; lubrication breakdown may be encouraged; and extrusion defects may form. All of these possibilities are important at the end of the extrusion, or even throughout the entire operation if short slugs are being processed as under cold or impact conditions.

The essential reason for *piping* is clearly brought out in Fig. 8. A 50-pct reduction in plane strain is represented as before; the ram advances at relative speed 1, and the extrusion must exit at speed 2. The steady-state zone is shown with the ram superimposed on it. The zone would, of course, have to be accommodated in the remaining billet, but the conclusion to be drawn from Fig. 8 is in order. The extruded material traveling to the right at speed 2 must move away from the ram face advancing only at speed 1. The result, therefore, is a pipe reaching forwards into the extruded piece. This defect may or may not be associated with the more usual one of billet skin working its way into the central parts of an extrusion. It can be of special importance in a class of operations given the different labels of back extrusion, piercing, impact extrusion, etc., which is the last topic to be discussed.

Piercing-type Operations: There are various operations of this sort, contrasting only in points of detail. For the plane-strain frictionless case, they are also directly related to extrusion as it has already been described. The similarities are pictured in Fig. 9. One imagines first that the slab extrusion is split lengthwise; then the halves are interchanged as shown; the two die pieces are fused into a punch; and finally, the old container walls are eliminated from along the center line and put out at the edges to form a new container. For the specified conditions, nothing basic has been altered. Dead metal now lies beneath the punch, and the extrusion force acts on a thinner punch, (H-h), instead of on a ram of thickness, H.

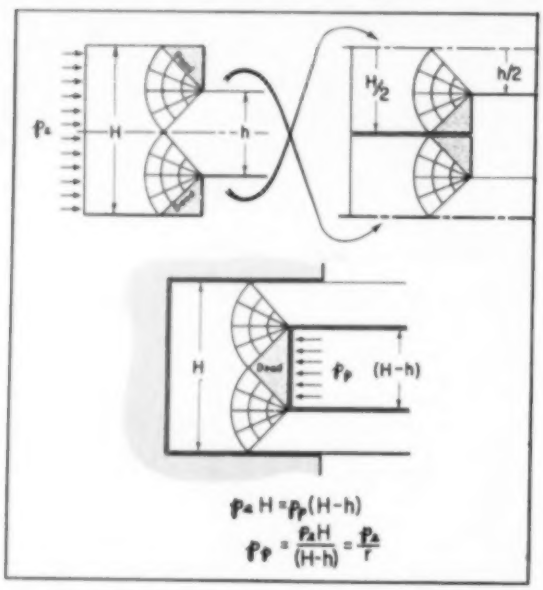


Fig. 9—Similarity between plane strain extrusion and piercing.

As the few equations demonstrate, a given reduction r = (H-h)/H requires a punch pressure, p_p, greater than that for extrusion, p_e. Knowing the variation of extrusion pressure with reduction (Fig. 7), it is a simple matter to show the change in piercing pressure. Fig. 7 also contains this relationship, p_p being given in the ratio $p/\bar{\sigma}$. An interesting point is that piercing is fundamentally a high-pressure operation; the highest pressures are found at small and large reductions with a minimum (about 2.5 $\bar{\sigma}$ for these conditions) about r = 50 pct. The close relationship of the trend to actual practice is shown in Fig. 10 where punch pressure is plotted for a range of reductions in the cold piercing, or slow-speed impact extrusion, of cylindrical 7075-0 aluminum-alloy billets with different initial length: diameter ratios.[9]

The piping described in connection with Fig. 8, also has its counterpart in piercing in the form of a *corner lifting* as the plastic zone spreads over the bottom of the container. If two piercing punches are coaxial and approaching from opposite directions, a circumferential depression encircling the part may even appear as plastic zones under the punches interact.[10]

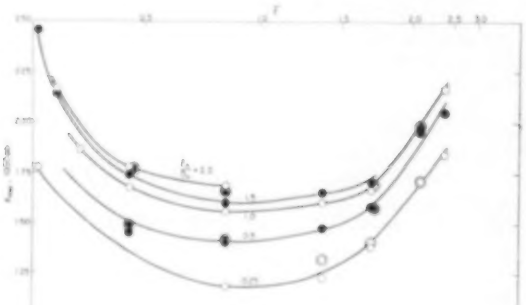


Fig. 10—Relationship between punch pressure and reduction in the cold piercing of cylindrical billets of aluminum alloy 7075-0, for different values of initial length:diam ratio. Reduction = $(A_o - A_1)/A_o$, where subscripts 0 and 1 refer, respectively, to initial billet cross-sectional area and final cross-sectional area of formed cup.

Summary

These remarks began with specifications of what a true theory ought to accomplish. Then there was an attempt to indicate something of where the theory stands now; various difficulties to progress were pointed out; and attention was drawn to the fact that some of these lie very much in the metallurgist's field of interest. Finally, a few examples were taken up simply to indicate how the theory looks in operation. In leaving this subject, one has to acknowledge that very few specific answers are possible for practical problems. But it is also important to recognize that good, although complex, theory is developing and is bound to become an increasingly useful engineering tool.

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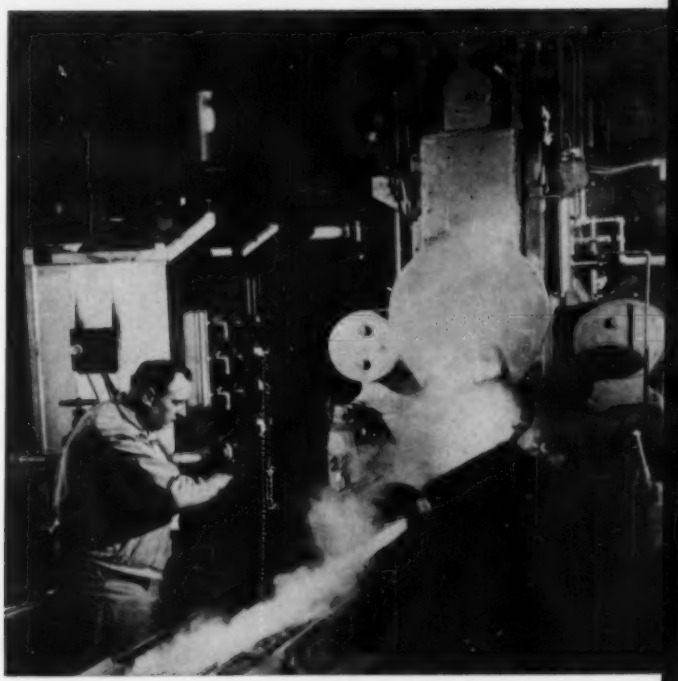
EXTRUSION OF STEEL

It has been predicted that extrusion will largely replace rolling to produce finished products within the next 100 years. This paper presents a brief review of the common extrusion methods, and cites specific production techniques for tubular and solid-shape steel extrusion.



2500-ton extrusion press at the Beaver Falls plant. Photo courtesy of Loewy-Hydropress.

Based on an article
by D. A. Edgecombe

Extrusion is relatively new among metalworking methods, probably because of the required delivery of considerable power at a high rate. Being one of the softest and most common metals, lead has been extruded for over 150 years and was the first metal so worked.

The modern concept of extrusion began in the 1890's with the extrusion of brass and other copper alloys. Years of intermittent development passed and in the late 1920's the Germans commenced commercial production of carbon steel pipe on mechanical presses. The significant contribution of Sejournet in the early 1940's was the development of the use of glass lubricants for high-temperature extrusions. There are currently more than six major producers of tubing and solid sections employing the licensed Ugine-Sejournet method of extrusion in the US alone.

Why extrusion?

The question is—why these producers decided to install the large presses required for extrusion? There are at least four reasons. First, extrusion usually provides superior surface and material yield in the forming of all common grades of alloy steels in the 300 and 400 series as well as many other difficult-to-form ferrous alloys. Secondly, many configurations of shapes and tubing which cannot be rolled can be made by extrusion. Third, the method is a very flexible production means and is ideal for handling *short runs* commonly occurring in the order pattern of the high-alloy trade. And finally, extrusion is one of the most satisfactory and economical tools for forming the refractory metals and their alloys.

The development of extrusion over the years has been rather slow, and it might even be more correctly stated that extrusion is an underdeveloped process. The development of the method has primarily been the solution of a series of mechanical problems. However, indispensable metallurgical contributions have provided improved hot-work steels for extrusion tools which have helped in the reduction of production costs. In addition, much work has been accomplished toward making better billet materials, although more work is needed in the development of better and more extrudable high alloys and exotic materials.

Types of extrusion

Basically, three methods of extruding steel are commonly employed: 1) forward, 2) inverted, and 3) piercing or back extrusion.

Forward extrusion: Fig. 1 provides a schematic diagram for this type of extrusion. An excellent example of forward extrusion press is a common item in the kitchen—a cake decorator. Cake icing can be extruded from this mechanism into the configuration desired by choosing the proper orifice or die. Into this decorator, we load the icing and push

D. A. EDGECOMBE is superintendent of extrusion, Babcock & Wilcox Co., Beaver Falls, Pa. This paper was presented at the Third Mechanical Working Conference, Pittsburgh, Jan. 1961. It will appear in the proceedings of the conference which will be published later in the year by Interscience Publishers, Inc. for The Metallurgical Society.

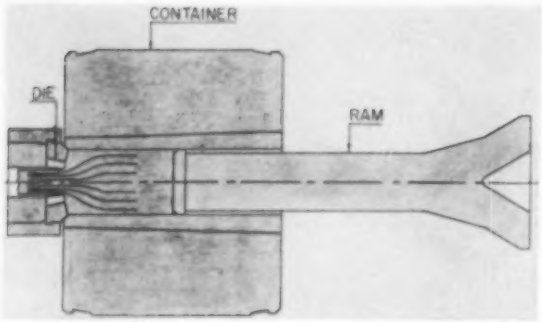
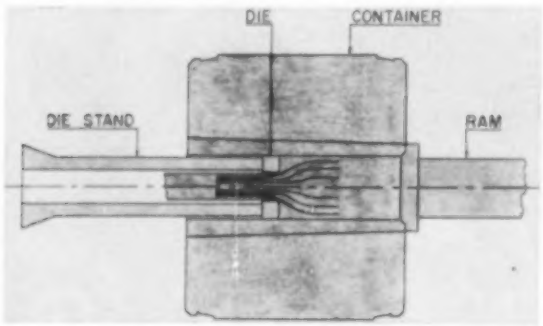


Fig. 1, Above—The forward extrusion method. Fig. 2, Below—The inverted extrusion method.



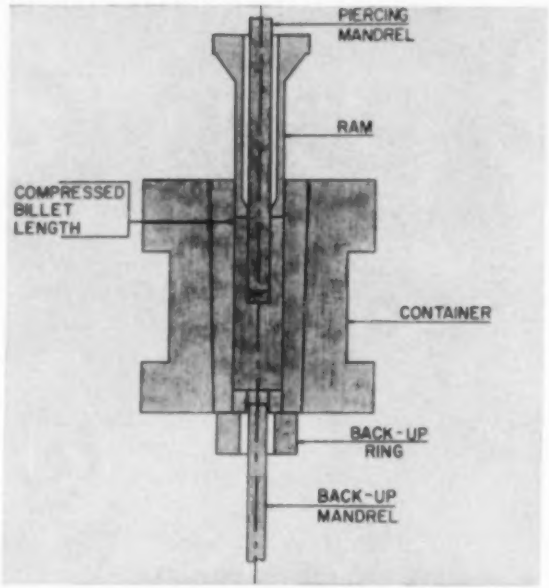


Fig. 3—The piercing or back extrusion method.

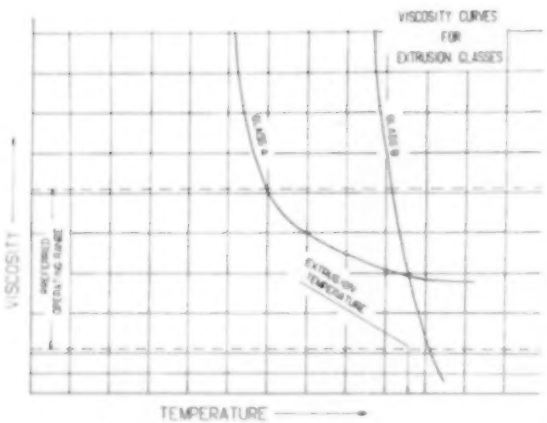
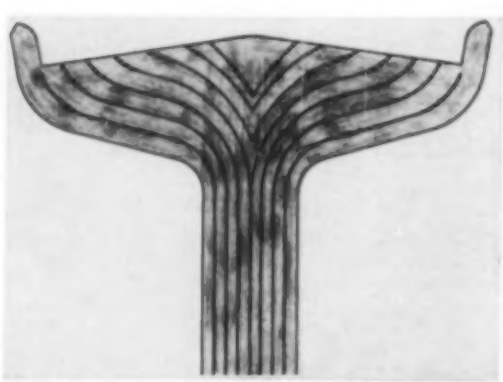


Fig. 4—Viscosity curves for extrusion glasses.

it out onto the cake or cookies. Obviously, in the case of a large press intended for the extrusion of steel, the billet is made plastic by the application of heat. In almost all cases, steel is extruded by the forward extrusion method.

Inverted extrusion: In the previous method, the ram pushed the billet through the container and into the die; this results in considerable power expenditure to overcome the friction between the billet and container. In the inverse extrusion method as illustrated in Fig. 2, the ram pushes the container and billet simultaneously toward the die, thus eliminating the relative motion between the billet and the container. Because of this lack of *sliding* along the container wall, no power is required to overcome friction. One serious limitation is that the extruded diameter can be no greater than the inside diameter of the die stand. This is a serious operational restriction except in the cases of the softer metals, such as copper and silver, where high reduction ratios present no problem.

Piercing or Back extrusion: This third method, illustrated in Fig. 3, is commonly used as a prepiercing operation which prepares hollow billets for



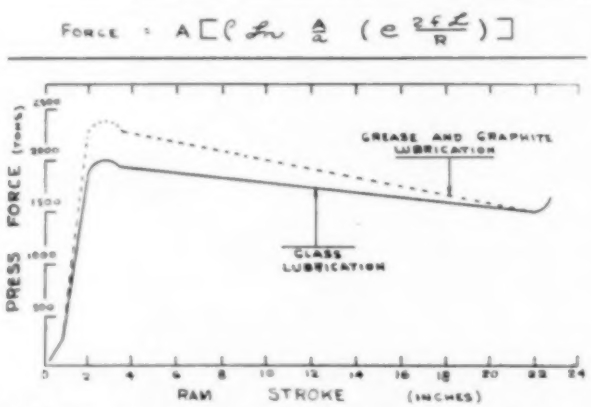
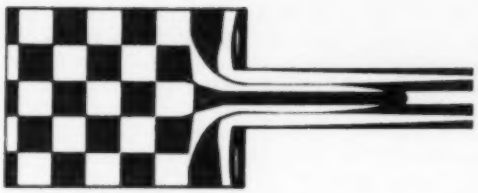


Fig. 5—Left, Extrusion butt from the forward extrusion method. Right, Pressure requirements for various lubricants in forward extrusion.



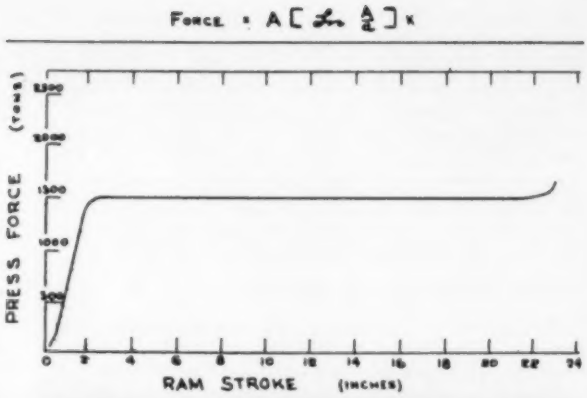


Fig. 6—Above, Flow which is representative of the inverse extrusion method. Right, Pressure requirements for inverse extrusion.

the extrusion of tubing. In this operation, the mandrel advances, pierces the billet, and displaces the metal in a backward direction; hence the name.

Lubrication

Basically, two types of lubricants are employed in extrusion: 1) a mixture of grease, graphite, and salt, and 2) glass. Grease mixture lubricants theoretically form a gas which then becomes the actual lubricating medium. However, most steel extrusion methods are lubricated by the patented Ugine-Sejournet process involving glass.

It is felt that glass is the superior lubricant for insulating the press tools from the billet. Being a viscous material, glass does not melt instantaneously; therefore, the glass in direct contact with the billet is the softest, and flows with the steel layer by layer. The glass layers not in contact with the steel form an unmelted reservoir, thus permitting longer and more difficult extrusions to be made. Glass lubrication is so efficient and complete that less power is required, and less damage to the dies and other tools is encountered. In addition, in the case where glass is used as a lubricant for the extrusion of austenitic stainless steels, the danger of carburization is eliminated. However, at this time the question of glass vs grease type lubricants could evoke lengthy debates involving considerations of material to be extruded, quality, costs, etc.

An important factor in glass lubrication is selection of a glass with the proper viscosity properties. Fig. 4 illustrates the viscosity curves for two extrusion glasses. Both glasses fall within the preferred viscosity range. However, when it is realized that an accurate extrusion temperature is difficult to attain due to variations in tool temperatures, handling time, and other factors, it is necessary to select a glass which has rather constant viscosity properties over a range of temperatures. Considerations of this type would result in the selection of "A" for this particular case.

Pressure and flow considerations

Some details of press force requirements and flow characteristics for forward extrusion are shown in Fig. 5. The graph of press force vs ram stroke indicates that the pressure requirement varies according to the progression of the ram through the stroke. As force is applied to the ram, the billet is compressed, and when sufficient pressure is built up to overcome starting friction, extrusion commences. Approximately 10 to 30 pct of the total power requirement is consumed in overcoming the friction

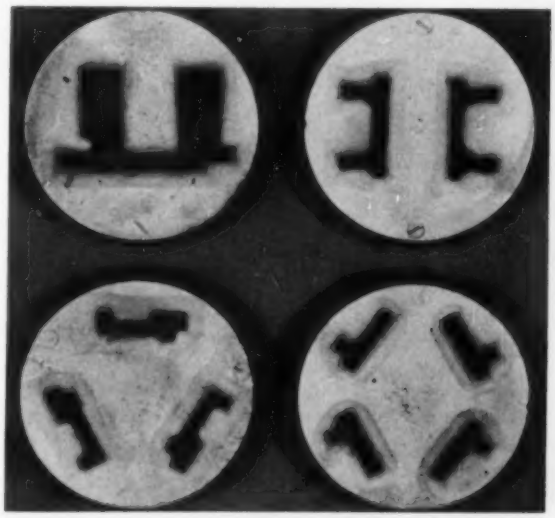


Fig. 7—One, two, three, and four port dies.

between the billet and the container with the remainder of the press energy being consumed in deforming the metal at the die. As the ram progresses and the billet becomes shorter, the pressure requirement steadily decreases, until it approaches the force level required for deformation only. The dotted and solid lines in the graph are intended to present a visual comparison of the pressure requirement for extrusion with the grease-type lubricant vs extrusion with a glass lubricant. It is obvious that less power is required for glass-lubricated extrusion. Or conversely, that for a given maximum of available press pressure, a much longer billet can now be extruded.

The sketch of an extrusion butt illustrates the characteristic of flow for forward extrusion. Because of the *sand hopper* effect or the tendency for the material to suck in faster at the center of the extrusion, piping is occasionally discovered along the axis at the back end of the bar. Although a fundamental problem, this defect can be minimized by the use of glass lubricants.

Fig. 6 presents the pressure curve and type of flow representative of inverse extrusion. As mentioned previously, no friction is generated between the billet and the container during the extrusion stroke; thus, as soon as the compression is complete, the pressure requirement remains constant throughout the completion of the stroke. The flat portion of

the curve represents rather precisely the force required to cause deformation of metal at the die. In practice, approximately 10 to 30 pct less pressure is necessary in an inverse extrusion as compared to a forward extrusion of the same reduction ratio.

The schematic diagram of billet flow through the die illustrates something very interesting. Each successive increment of billet advances toward the die without appreciable deformation. At the die, deformation is almost instantaneous; thus, there is no tendency for internal piping defects to form.

Tube and shape extrusion

Extrusion of tubes and solid shapes is essentially performed with the same operations except that, in the case of tube extrusion, pre-piercing is necessary.

The first step in the extrusion of steel is to heat the billet to the desired temperature range in a rotary-hearth, gas fired furnace. Temperatures vary from 2100° to 2300°F, depending upon the material in tube extrusion, and average about 2000°F for shape extrusion. Prior to heating, stainless steel billets are dipped into a high-temperature enamel which protects them against scale formation during heating. As the billets move through the furnace, this enamel forms a protective glass-like coating. During serious breakdowns, billets have been held in the furnace more than 7 hr without any scale formation.

For tube production, the second step is pre-piercing, which is performed on a 500-ton verticle piercing press utilizing the back extrusion method illustrated in Fig. 3. The use of glass as a lubricant requires that the billet be provided with a hole through its center, slightly larger than the extrusion mandrel in order that the glass will not be removed as the mandrel is inserted into the billet. All billets are pre-pierced as a matter of economy. The advantage of back extrusion is the amount of billet material saved as compared to a boring process. During this operation, the billet surface is lubricated by rolling it through a bed of ground glass, and the piercing point is lubricated by placing ground glass on the end of the billet.

Reheating of billets for both tube and shape extrusions is performed on a 60-cycle, 400-kw induction heater. The induction heaters represent the second attempt to find a suitable reheating means. Formerly, a mammoth salt bath was employed, but with the advent of the induction heater, the changeover was made. As the billet leaves the induction heaters, the mandrel lubrication—a scoopfull of ground glass—is inserted into the pierced hole of the billet.

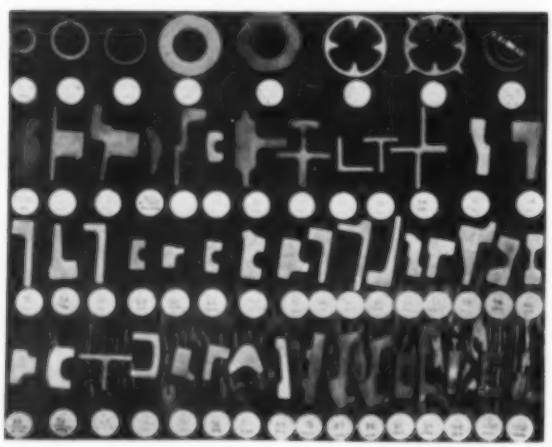


Fig. 8—Typical extrusions produced at Beaver Falls.

Prior to the arrival of the billet at the press, the die lubricant is inserted. The lubricant, a solid disc usually formed from scrap ground window glass, is placed flush against the die in the container. Upon arrival, the billet is pushed into the container of the 2500-ton Loewy extrusion press. On this press, high alloy steel tubing is commonly extruded by the forward method at a rate of 6.5 tons per hr, and 7.5 tons per hr for shapes from all grades of steel. Actually, these production rates are limited by furnace capacity rather than by the press itself. A rate of 15 tons per hr on this press would not be unrealistic. The hydraulic press and the companion pre-piercing press are collectively powered by two 800-hp pumps each supplying 296 gpm of water. Since this power must be delivered in a relatively short span of time, 3600 psi of water is stored in two large accumulators. It is interesting to note that, if a direct drive were used to power the extrusion presses, a motor with a 6000-hp capacity would have to be employed for the extrusion press alone.

After extrusion, the material is either sawed or sheared from the discard or butt and then passed to a cooling bed or quench tank as required. Shape extrusions are finished on a 150 ton stretch straightener and inspected before shipment.

Shapes

It is interesting to examine some of the die designs. Whereas our tube tools are standard, the shape dies are unique. As illustrated in Fig. 7 dies of one, two, three, or four ports are utilized. Use of these multi-port dies permits easier extrusion of *difficult-to-extrude* materials, attains high tonnage production rates, and eliminates the need for billets of varying diameters and press changeovers. In addition to the ability to fabricate shapes unattainable in a rolling operation, we feel that this extrusion press is the world's most flexible *rolling mill* because it can extrude two radically different shape designs with a 6 min allowance for changeover. Fig. 8 presents some of the shapes extruded at our plant. Extruded sections or shapes can be as small as 0.6 sq in. or of any larger area which will fit into a 6½ in. diam circle.

Future

The outlook for the extrusion of steel may best be indicated by a statement of Benjamin Fairless in 1956. Mr. Fairless attempted to visualize the technological advances that would occur in the steel industry over the next 100 years. Among other comments, he stated that, "Extruding will largely replace rolling to produce finished products". The events of the last few years have already lent considerable credance to his statements; in the realm of extrusion, a considerable amount of advanced thinking is now coming to the fore. In fact, in both Europe and the US, some very practical large extrusion presses are now on the drawing boards or under actual construction. These large presses—3300 to 4400 tons—represent the most likely means of improving the quality of tubular products, production rates, and costs in the production of all grades of steel tubing.

OXYGEN REFINED FERROALLOYS

Successful in steelmaking, oxygen top-blowing techniques are now being employed for the refining of ferrochrome. This may be the beginning of the wide-spread use of oxygen in the ferroalloys industry.

Taking its cue from the LD, basic oxygen steelmaking process, the ferroalloy industry has begun utilizing oxygen for the refining of ferrochrome.

For Union Carbide Metals Co., the development of oxygen refined ferrochrome is the culmination of several years of experimental work at the Marietta, Ohio, plant. Starting material is an intermediate-grade of ferrochrome produced in a one-stage smelting operation in submerged arc furnaces. Analysis of this material is approx as follows: 68-71 pct Cr, 5-6 pct C, 2-3 pct Si, and 0.07 pct S. Oxygen refining reduces carbon to a max of 4.25 pct, silicon to a max of 1.00 pct, and sulfur to a max of 0.03 pct, with chromium between 58 and 65 pct.

In the new process, ferrochrome, tapped from a submerged-arc furnace into ladles, is transported to the oxygen refining post where a hood is placed over the ladle. A vertical, water-cooled copper lance is lowered into position over the ladle containing from 8000 to 10,000 lb of ferroalloy. Blowing commercially-pure oxygen at the rate of less than 1000 cu ft per min requires from 30 to 40 min. During the cycle, lime is added to form a slag. Considerable fume is formed and carried out through the hood into a dust-catching installation. The overall cycle, including pouring the refined ferrochrome into chills, is a matter of about 1 hr. The slag, because of its high chrome content, is returned to the submerged-arc smelting furnaces.

Another firm is active in this same field. At the Beverly plant of Interlake Iron Corp. oxygen-refined ferrochrome has been in commercial production since early 1960 with some 2500 tons made thus far. Their operation is quite similar to that of Union Carbide with carbon reduced from 5.5 or 6 pct to a max of 4.25 pct and silicon to 1 pct max. While marketing this product, Interlake is also producing a max 2-pct silicon ferrochrome which is the result of deoxidizing the melt with chrome silicide in order to recover chrome which would otherwise be lost in the slag unless it were resmelted.

Advantages

Refined ferrochrome is a low-cost source of chromium charge material for stainless steels. It is of particular interest to stainless producers because its comparatively low carbon and silicon contents allow large additions of chromium to the base charge. It is a lower cost material, because it is less costly to reduce the carbon and silicon contents of ferrochrome by oxygen blowing than it is to produce the same grade of material in a double-stage furnace operation.

Oxygen refining ferrochrome at the Marietta, Ohio, plant of Union Carbide Metals Co.

Oxygen injection causes intense agitation of the molten charge at elevated temperatures which serves to homogenize the melt and remove deleterious gas. The result is a more uniform, more dense product. Furthermore, the higher temperatures and added time in the molten state allow for the removal of impurities. Finally, in oxygen-blown ferrochrome, reactive elements, such as titanium, are substantially removed. The overall result is a better product.

General application

These reasons should add up to a general adoption of oxygen refining for the production of lower-carbon grades of ferrochrome. And this appears to be the case. In addition to Union Carbide and Interlake, other firms are also moving into this same area of oxygen refining. Vanadium Corp. of America has been conducting extensive tests and is reported ready to exploit the practical aspects of this process.

Thus, it appears that oxygen refining of ferrochrome will be adopted on an industry-wide basis. The introduction of oxygen to ferrochrome production bodes well for a far wider application of oxygen to other ferroalloys. The door is opening, and oxygen may begin to revolutionize the ferroalloy industry as it has done with the steel industry.

F. Weston Starratt

OXYGEN JETTING SECONDARY COPPER

A description of experimental work on a top-jetting oxygen process, designed to replace the conventional method of converting black copper to rough copper in an air-blown Peirce-Smith converter.

by W. S. Nelmes, J. A. Charles, and A. G. Cowen

For many years metallurgists have wished to use oxygen instead of air for the combustion of fuel and oxidation of impurities in metal refining. With improvements in methods of oxygen production and distribution, this desire has become an economic possibility in many fields, particularly in the iron and steel industry.

Because the unit sizes of copper works are much smaller than the majority of steelworks, the individual demand for oxygen will be much smaller and the cost higher. The amount of copper residues and scrap arising in the UK is limited; therefore, it is not possible to build large plants with high outputs to lower treatment costs per ton. The savings must come from the lower capital expenditure possible when small furnaces having high outputs are installed.

The advantages obtained when using oxygen for refining are numerous, but the most important one is the increase in thermal efficiency achieved from smaller gas volumes. Greater control of furnace atmosphere is possible, and due to the absence of nitrogen, the oxygen present is more effective in reactions. Provided practice is modified to use higher temperatures, the replacement of air by oxygen enables plant capacity to be increased and gas filter plant to be reduced in size.

Smelting and refining secondary copper

The secondary copper plant has four main production units, whose relationship is shown in the flow sheet, Fig. 1. These units are: blast furnace, converter, anode furnace, and electrolytic refinery.

The blast furnace is used to smelt copper slags, residues, and intermediate slags and drosses produced by the converter and the anode furnaces. A crude copper, termed *black copper*, is formed; it has the following approximate analysis: 70–75 pct Cu, 5-10 pct Sn, 3-5 pct Zn, 2-4 pct Fe, and 2-4 pct Ni. A final low-copper slag is dumped, and a high zinc-oxide fume, recovered from the furnace gases, is sold.

The converter receives the molten black copper from the blast furnace together with contaminated gun metal and tin-bearing metal. The charge is refined by oxidation to *rough copper*. A high copper and tin bearing slag is recycled to the blast furnace for recovery of the metal content. Converter fume, containing 15-20 pct Sn as an oxide, is sold.

The anode furnace is an oil-fired rotary furnace which receives rough copper from the converter together with high-quality scrap (90-95 pct Cu). The charge is refined by oxidation and the metal cast into anodes (98.5 pct Cu) for the refinery. Here the anodes are electrolytically refined to cathodes (99.9 pct). By-products are crude nickel sulfate and anode slime, containing the precious metals recovered from the residue and scrap intake to the smelter. The thin plate of anode copper, which is left after the anode has been corroded, is returned to the anode furnace for remelting.

The aim of the research work described in this paper was to determine whether the present converters could be replaced by a smaller vessel using oxygen.

The converter plant, shown in Fig. 2, has two main metallurgical aims. The first is to permit, by rapid refining, the intake of a larger amount of metal than is possible in a reverberatory furnace of similar nominal capacity. The second is to recover the tin as a fume, but unavoidably, lead and zinc also pass into this fume. Oxidation in a reverberatory or similar type furnace results in most of the tin passing into the slag, thus increasing the recycling load.

Sufficient zinc, tin, and lead must be present in the charge to provide, by their oxidation, the heat required to enable the furnace to function.

The converter vessels at Elkington Copper Refiners Ltd. are Peirce-Smith type furnaces lined with magnesite refractories. The internal dimensions are 10.5 ft long by 5 ft diam. Twelve 1-in. diam. tuyeres are positioned at the bottom of the furnace, much lower than in the conventional matte furnace to avoid blowing into the slag and freezing it on the tuyere panel. This size furnace has a nominal capacity of 10 tons and completes its refining cycle in 4 to 5 hr. The air for blowing is provided at a pressure of 15 to 20 psig and a rate of 3000 cu ft per min by three compressors, each of 80 to 90 hp.

The solid portion of the charge is melted first with coke before the hot metal from the blast furnace is added; the required coke amounts to 15 to 17 pct of the charge weight.

When the use of oxygen in the converter was first contemplated it was thought that oxygen enrichment of the blast would suffice but, due to a series of burn-outs of the tuyere panels caused by excessive temperature in normal operation, it was

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considered unwise to proceed. Oxygen added to the blast increases the tuyere temperature and erosion; thus, the advantages of quicker blowing are nullified by more extensive repairs. Furthermore, tuyere punching might still be necessary, and the thermal efficiency remains low due to the presence of nitrogen.

It was, therefore, decided to go ahead by lancing or jetting oxygen into an upright vessel. No tuyeres are used and punching is thus avoided. Greater control of temperature is possible by the more accurate control of the oxygen input. No air compressors are used, and the process operates much more speedily.

The oxygen injection trials were carried out to establish: 1) The efficiency of impurity elimination, 2) The quantity of oxygen required per ton charged, and 3) The economic advantages if any.

Preliminary work

Preliminary experiments on a 100-lb scale were carried out at British Oxygen Co.'s Scientific Center in order to assess the general practicability of the process and to discover any particular difficulties associated with oxygen refining. Various methods of introducing the oxygen were also investigated.

Black copper was made up for the experiments from scrap copper with additions of iron, lead, tin, and nickel to approximate a metal composition such as might be obtained from smelting residues in a blast furnace. The mixture was melted in a crucible furnace and transferred to a magnesite-lined, converter-shaped ladle. Blowing took place under a fume hood, and samples were poured into a copper mold for subsequent drilling.

Several types of oxygen probes were investigated, including a mild steel 5/16-in. inner diam submerged lance, uncoated and refractory coated; a submerged lance ⅜-in. inner diam Salamander; and a top-jetting 7/16-in. copper parallel bore nozzle, refractory coated. The method of refractory coating the probes was to wind them with asbestos string and coat the string with a thick magnesite slurry to a total diam of 2½ in. The submerged lances were maintained a few inches below the surface during blowing, while the distance of the jetting probe above the surface was varied between ½ and 3 in.

It was established that the most satisfactory of the methods tried for introducing oxygen was top jetting with a refractory-coated probe. In the tests where submerged lances of the types mentioned were used, the burn-off rate was so high that control of the length submerged was difficult. With a longer blowing period such as would be necessary on a larger scale, it seemed probable that the probe would require changing at least once during the blow.

Detailed experimental results are not presented, since only a limited amount of information was sought from the tests, and comprehensive analysis of fume, metal, and slag was not undertaken. Furthermore, there was no significant metallurgical difference between the results of top jetting and submerged lancing.

The composition of black copper made up for the experiments was within the following limits: 2.5-5.0 pct Fe, 3.5-5.0 pct Pb, 0-3.0 pct Sn, and 0-3.0 pct Ni. Zinc was not added, because of local difficulties over fume collection, but no trouble was anticipated in its removal.

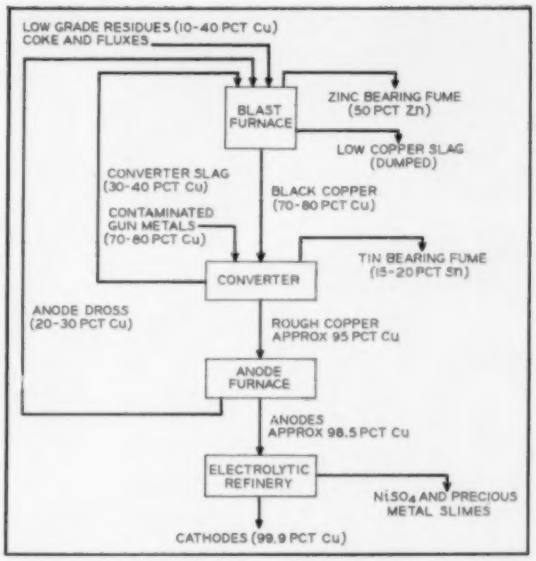

LOW GRADE RESIDUES (10-40 PCT Cu)
COKE AND FLUXES
BLAST FURNACE
ZINC BEARING FUME (50 PCT Zn)
LOW COPPER SLAG (DUMPED)
CONVERTER SLAG (30-40 PCT Cu)
BLACK COPPER (70-80 PCT Cu)
CONTAMINATED GUN METALS (70-80 PCT Cu)
CONVERTER
TIN BEARING FUME (15-20 PCT Sn)
ANODE DROSS (20-30 PCT Cu)
ROUGH COPPER APPROX 95 PCT Cu
ANODE FURNACE
ANODES APPROX 98.5 PCT Cu
ELECTROLYTIC REFINERY
$NiSO_4$ AND PRECIOUS METAL SLIMES
CATHODES (99.9 PCT Cu)

Fig. 1—Smelting and refining processes of Elkington Copper Refiners.

In the experiments, no special difficulties were encountered in bringing iron and tin down to the required level. It is desirable to keep as much nickel as possible in the blown copper when it can be recovered in subsequent electrolytic treatment, and this was achieved except when the blowing period was unduly prolonged. Lead was brought down to the required level only when silica was added to the slag as in conventional practice. It had been hoped that silica would not be necessary because of the disadvantages of the resulting large slag volume. Appreciable lead removal did not occur in any case until the iron content was below 1 pct. The silica addition could, therefore, be postponed until most of the iron had been removed and the metal was sufficiently hot for a reasonably fluid silicate slag to be formed quickly. Towards the end of the blow, oxidation of copper proceeded rapidly, and coke was added to the surface to prevent this becoming excessive.

On the basis of these experiments it was decided that the process was generally practicable and that a refractory-coated copper jetting probe was a satisfactory means of introducing oxygen.

Elkington's trials

Field trials were carried out on 1-ton batches of black copper for which purpose a tilting crucible-furnace was fitted with a conical nosepiece and lined with refractory. An external view of the furnace is shown in Fig. 3.

The lining consisted of ½-in. insulation with 4½-in. magnesite brick for the sides and 6 in. of magnesite brick for the bottom. The dimensions were such that the depth of copper was about 12 in. Fume was extracted via a fume hood and duct into the main duct to the bag house.

The jetting probes were made up in similar fashion to those at British Oxygen, using 6-ft lengths of 5/16 in. inner diam copper tubing, with asbestos string wound over the entire length and refractory (mag-

Fig. 2—Left, 10-ton converter for the treatment of secondary material at Elkington Copper Refiners Ltd. in England.

Fig. 3—Opposite page, 1-ton converter for oxygen jetting trials.

nesite) coated for 4.5 ft to a total diam of 2½ in. They were coupled to mild-steel tubing.

Black copper from the hot metal mixer was weighed in a ladle and charged to the converter which was turned down for the purpose. Blowing began as soon as the converter had been turned up into the fume hood.

The rate of oxygen injection had been provisionally calculated on the basis of a 45-min blowing period by estimating the volume of oxygen required to convert a typical black copper, assuming 50 pct oxygen efficiency. A blowing rate of 50 cu ft per min was originally employed and adjusted as required. It was necessary to stop blowing and turn the converter down for temperature measurement and sampling. Progress was judged by the appearance of the fracture samples.

The trials can be conveniently grouped into three series of which the first was mainly concerned with testing the equipment and gaining operational experience. During the second series, the rate and pattern of oxygen injection was varied to discover the optimum blowing procedure. From the results of these series an operating sequence was developed, and this was employed for the third series.

Since it was not practicable to obtain a hot-metal analysis before blowing, such a sequence had to be capable of being applied to black copper having a wide variety of individual and total impurity contents. The sequence, outlined below, was adopted as offering the best compromise:

1) Charge 1 ton black copper (temp about 1100°C),
2) Blow for 8 min at 60 cu ft per min (At the end of this period the temperature was of the order of 1400°C, and most of the iron and zinc had been removed.),
3) Continue blowing at a reduced rate of about 50 cu ft per min or less, depending on the estimated temperature, and add 100 lb silica over a period of 5 min,
4) Stop blowing after a total of 1800 cu ft had been introduced, then turn down converter for sampling, and
5) Add 30 lb coke to the metal to protect the copper from oxidation.

The volume of oxygen required to complete conversion was estimated from the fracture sample. The blowing rate was reduced if the temperature was more than 1500°C.

Results

The results of the three series are considered separately. In the first series, the blows were carried out without silica additions to avoid excessive slag formation. All of the impurities, apart from lead, were reduced to within the required limits. The failure to reduce lead to the required limit (about 0.8 pct) was due to the absence of silica from the slag.

Work at British Oxygen had shown that lead removal did not commence until iron had been reduced below 1 pct, and the first series of trials had shown that about 120 cu ft of oxygen per ton of black copper was required to reduce the iron content by 1 pct. In the second series of tests, silica addition was delayed until about 500 cu ft oxygen had been introduced by which time the iron content of the general run of black copper was below 1 pct. Satisfactory lead removal was achieved during this series. A typical refining graph for the oxygen process is shown in Fig. 4; it is similar to a refining graph for the conventional process shown in Fig. 5.

Table I. Metal Balance Blowing Black Copper with Oxygen

	Initial Metal		Final Metal		Loss		O_2 Required
	Pct	Lb	Pct	Lb	Lb	Pct	Cu Ft
Cu	81.80	1924.0	96.76	1524.0	400.0	20.8	
Sn	5.82	137.1	0.12	1.9	135.2	98.5	378
Pb	6.15	144.5	0.59	9.3	135.2	93.5	139
Fe	1.27	29.8	0.09	1.4	28.4	95.2	98
Ni	2.52	59.2	1.04	16.4	42.8	72.5	141
Zn	1.93	45.4	tr	—	45.4	100.0	150
Sb	0.37	8.7	0.17	2.7	6.0	69.0	14
Others	0.14	3.3	1.23	19.3	−16.0		
Total	100.00	2352.0	100.00	1575.0	777.0		920

The maximum blowing rate permissible is controlled by thermal considerations. During the series, the initial blowing rate was varied between 50 and 100 cu ft per min. With a blowing rate of 60 cu ft per min throughout, the conversion time was 40 min for a black copper assaying 75.14 pct Cu. The maximum blowing rate used was 100 cu ft per min for 19.5 min, followed by 7 min at 80 cu ft per min after coke had been added, and finally 2 min at 95 cu ft per min. At the end of this blow, the lining failed and the metal had been overblown, particularly with regard to nickel, to a final analysis of 0.41 pct Ni from a nickel content of 3.56 pct. The results of this blow emphasized that the rate of oxygen introduction should be reduced after coke is added, since surface temperatures are then very high. This period should also be kept as short as possible.

It was also found necessary to restrict the blowing rate to about 60 cu ft per min for the first period during which iron and zinc were removed and the metal temperature rose from about 1100° to about 1400°C. To avoid overheating, the rate was reduced to about 50 cu ft per min while the silica was added and lead and tin were being removed. Silica was added over a period of 5 to 6 min to avoid crusting the metal surface. The resultant cooling, coupled with the reduced blowing rate, prevented too rapid a temperature increase. The converter was turned down for sampling after a total of 1800 cu ft oxygen had been blown; the temperature was generally about 1500°C. It was found that a further 3 to 6 min blowing, under coke cover at reduced rate was usually sufficient to complete conversion.

Table II. Distribution of Impurities Between Slag and Fume*

	Slag		Fume
	Pct	Lb	Lb
Cu	48.60	504.5	—
Sn	9.42	97.8	37.4
Pb	10.11	105.0	30.2
Fe	2.79	29.0	—
Ni	3.46	35.9	—
Zn	3.59	37.3	8.1
SiO_2	9.44	98.0	—
Sb	0.24	2.5	3.5
Total	87.65	910.0	

* Assuming a slag wt of 1040 lb.

The operating procedure previously outlined was applied to three consecutive blows. Since the copper assay of the black copper was running about 80 pct at this time, the blows were interrupted for sampling after 1500 to 1700 cu ft oxygen had been blown. A summary of the overall results of the three blows shows an oxygen efficiency of 54 pct, copper yield of 74 pct, tin elimination of 56 pct to slag and 42 pct to fume, and nickel retention of 30 pct.

The oxygen efficiency is taken as the volume theoretically required for the elimination of Sn, Pb, Fe, Ni, and Zn divided by the total volume used. If the volume of oxygen required to oxidize the copper in the slag and to burn the coke is added to that required for the elimination of impurities then 90 to 100 pct of the oxygen used is accounted for, indicating that only a small quantity of oxygen, as such, leaves the furnace.

A metal balance for one of the three final consecutive blows is shown in Table I. The measured slag weight was subject to considerable error and was, therefore, derived from known weights of copper, nickel, iron, and silica in the slag. In this manner, the derived slag weight for the blow shown in Table I, was approx 1040 lb. The distribution of impurities between slag and fume for this same blow is shown in Table II. For this blow the total oxygen blown was 1700 cu ft, as compared with theoretical requirements of 920 cu ft, thereby yielding an oxygen efficiency of 57 pct.

Discussion

Although the pilot-scale trials were not extended to a systematic investigation of all the variables inherent in the process, sufficient information was obtained to permit an assessment of oxygen conversion as compared with conventional practice.

There appears to be little difference in the metallurgical problems involved in the two methods of converting secondary copper.

The removal of lead in the oxygen process still required the addition of silica, as in normal practice, to attain the final required content of 0.8 pct.

The oxidation of iron was, as expected, extremely rapid when using oxygen. This was an advantage as the temperature of the black copper is only sufficient (1100°C) to enable it to be satisfactorily poured from the holding furnace to the vessel. Excess temperature of the molten black copper leads to fuming and consequent loss of tin during holding and transport before conversion. The rapid oxidation of iron quickly raises the temperature in the converter, thus tending to prevent the formation of magnetite which is produced at temperatures below 1200°C. If formed, magnetite settles on the lining of the furnace and, with slag, forms a build-up which has to be removed with pneumatic chisels when cold. A higher silica content will reduce magnetite formation, but in the normal converter insufficient heat is developed to take the silica into the slag. Due to the shorter blowing time and more rapid heat development, it is possible to use more silica when blowing with oxygen. This did not

prove necessary, however, because the higher temperature either prevents the formation of magnetite or enables it to be held in solution in the slag and removed from the furnace. The addition of silica has to be kept at a minimum as it increases the weight of the slag which has to be retreated.

Zinc presents no problems when treating black copper and gunmetal. It is mainly volatilized and oxidizes near the mouth of the furnace. Up to 6 pct Zn is found in the slag.

Some nickel is oxidized into the slag and recycled to the blast furnace. The proportion of nickel remaining in the blown copper to be recovered as $NiSO_4$ during subsequent electrolytic refining is approximately the same as in the conventional process.

The most important aspect of the converter process is the elimination of tin, which is derived mainly from low tin bearing residues. The figures indicate an initial recovery as fume of 42 pct, which is similar to that obtained in the conventional process. This figure may appear low, but it is necessary to maintain a certain amount of tin in the black copper by recycling so that the tin:zinc ratio in the fume is as high as possible. Without the recycling of tin, i.e. with a low-tin black copper, the tin content of the fume would be in the 5 to 10 pct range. By recycling and the elimination of zinc in blast furnace, the tin content of the fume is increased to the 15 to 20 pct range. This is a considerable commercial asset since a high tin content is desired by the secondary tin smelters. The overall tin recovery in the smelter exceeds 80 pct.

The oxidation of copper into the slag is a greater problem when using oxygen, but surface additions of coke and the careful control of the rate of oxygen input enables the copper content of the slag to be kept in the same range as in the normal method of converting.

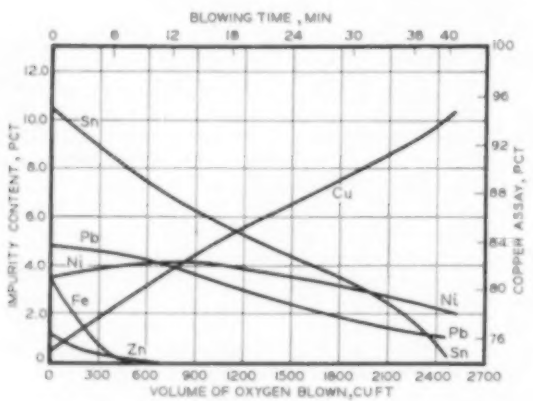
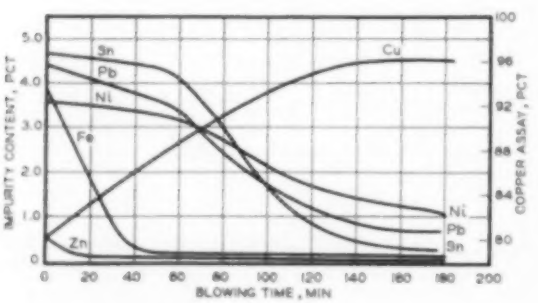


Fig. 4—Above, Typical refining graph for oxygen process. Fig. 5—Below, Refining graph for conventional process.



Use of Oxygen

The blowing pattern evolved, in which the blow was only interrupted once for sampling, gave satisfactory results with a variety of starting compositions. But the total oxygen requirements vary between 1600 and 2400 cu ft per ton according to the grade of black copper; therefore there is the danger of either overblowing the metal, with excessive loss of nickel, or of not removing the impurities to the required limit. It is not practicable to obtain a complete analysis before starting, but if the hot metal were assayed for copper, a fair estimate of the total oxygen requirement could be made and the best time to interrupt the blow for sampling determined. There do not at the moment appear to be any external physical effects, such as change of flame color, by which the progress of the blow could be judged.

Oxygen efficiency was about 50 pct and, if the oxygen consumed by coke and copper was considered, 90 to 100 pct of the oxygen used was accounted for. It is unlikely, therefore, that the oxygen efficiency could be raised much above the present level, although some improvement might be expected on a large-scale furnace.

The introduction of oxygen through refractory coated probes, while an acceptable method for trials, cannot be regarded as finally satisfactory. The consumption rate was subject to considerable variation, making frequent adjustments of the probe necessary. A water-cooled probe would be required for a production furnace.

General

The advantages of an oxygen process, such as has been described, over the conventional air-blown converter process are as follows:

1) The furnace is simpler in design and cheaper; there are no submerged tuyeres with their attendant problems in punching and replacement;
2) Blowing equipment is not required;
3) The exhaust volume could be reduced and less filter area would then be required;
4) The amount of coke required is reduced from about 15 pct to 2 pct of the charge weight; and
5) The oxygen process is considerably faster.

These advantages have to be set off against the cost of the oxygen and maintenance of the jetting probes. The assessment made on the basis of these trials showed that the operating costs of the two processes (including refractories) are similar. However, the capital costs of the oxygen process would be considerably lower.

Conclusions

Although the trials were not sufficiently extensive to permit a complete evaluation of the oxygen process, it can be concluded that it is an entirely satisfactory method of converting black copper to rough copper. The operating costs are similar to those for the conventional process, but the capital cost for the oxygen process would be considerably lower.

PHILIPPINES' FIRST COPPER

A combination of ammonia leaching, hydrogen reduction, and powder compacting (AHC) is to be the basis for the Philippines' first copper producing plant.

by F. Weston Starratt

With an annual production of more than 50,000 tons of copper in ores and concentrates, the Philippines has no facilities for the transformation of these raw materials into metallics. The majority of the concentrates are smelted in Japan.

In this mining picture, Marinduque Iron Mines Agents Inc. occupies a prominent position with two principal mining operations producing copper concentrates at a combined rate of 75,000 tons per year. One of the operations is the Sipalay property on the island of Negros; it produces 35,000 tons per year of chalcopyrite concentrates containing about 23 pct Cu, 22.5 pct Fe, and 29 pct S. The second large copper operation is the Bagacay property on the island of Samar; its output amounts to 40,000 tons per year of a concentrate containing 17 pct Cu and 13.5 pct Zn—too much zinc to be desirable feed for conventional copper smelters.

Eager to process its own concentrates into metal, Marinduque was faced with several problems, most of them economic. First, a conventional copper smelter and electrolytic refinery would not be economic within the limits posed by the output of the mines—50 tons of copper per day; operating costs would be high and capital costs prohibitive. Secondly, capital costs for conventional facilities for producing strip and tubing would not be practical for such a limited output. Furthermore, while the copper-zinc concentrates were amenable to leaching, they were not readily adapted to conventional treatment. Clearly a non-conventional approach was needed.

Sherritt-Gordon's approach

But unconventional approaches have been attempted, possibly not directly on copper, but on the treatment of complex ores containing copper. One attempt, which succeeded, was that of Sherritt-Gordon Mines Ltd. for the treatment of a complex nickel-cobalt-copper ore body at Lynn Lake, Manitoba, Canada.[1] Examination of possible treatment methods for concentrates from this orebody was undertaken in 1947 by F. A. Forward and his coworkers at the University of British Columbia; within a year they found that an ammonia leach would do the job. Chemical Construction Corp. was brought in to discuss the design of a pilot plant. Independently, this firm had been studying pressure leaching of sulfide ores with acid solutions. More important, they had discovered a means of nickel precipitation from ammoniacal solutions by using hydrogen under pressure.[2] When these two steps were brought together the final process began to take shape: an ammonia leach as developed by Sherritt-Gordon, followed by Chemico's pressure hydrogen precipitation procedure to recover nickel and cobalt metal from the solution. Copper, which was contained in the leach solutions, was precipitated as a sulfide. Culmination of the research and pilot-plant work was the construction of Sherritt-Gordon's Fort Saskatchewan refinery which started operation in 1954.

Chemical Construction Co., then a subsidiary of American Cyanamid Co., has since been sold and its patent rights for this process have been acquired by Sherritt-Gordon. Chemetals Corp. is a licensee.

Powder compacting

Output of the ammonia leach – hydrogen reduction process is in the form of powder; hence, it was only natural that further development be directed toward the compacting of this powder into strip and other useful forms. Taking its lead from early German experimental work done by Mannesmann and Sundwiger Messingwerk—which companies licensed Chemetals to use their basic rolling patents—Chemetals enlisted the aid of E. W. Bliss Co. to develop equipment and techniques for the continuous rolling of strip from copper powder. In 1958 it was announced that a process for the production of high-quality copper strip from powder had been developed. This strip was claimed to be equivalent to strip produced from ingots by conventional rolling equipment. Much of the copper powder rolled by Bliss was produced by Whitaker Metals Corp., a licensee of Chemetals, and was deemed to be highly suited as a feed material for the rolling technique.

The next logical step was to put together these two operations—leaching-reduction into powder followed by rolling of strip—into one integrated process. Sherritt-Gordon has been moving toward such an integrated operation for the production of nickel strip, on the basis of their own developmental work on rolling[2] and that of Chemetals utilizing Bliss equipment, but this is still in the development stage.

Meanwhile

Marinduque, in its quest for a means of producing metallic copper from its ores, investigated numerous processes and finally settled on the Sherritt-Gordon Chemetals process. Concentrates were sent to Fort Saskatchewan to test ammonia leaching, zinc separation, and reduction; compacting and rolling of the resulting copper powder was also tested. After 18 months of detailed studies, the suitability of the Marinduque concentrates for this type of treatment was proved.

The announcement

The result of these and other efforts in the realm of finance and engineering was the January 31st announcement that the Export-Import Bank of Washington had authorized a $13 million credit in favor of Marinduque Iron Mines Agents Inc. of Manila. The approved funds are to be used to cover the costs of US equipment for an integrated copper and zinc extracting and fabricating plant at Iligan Bay on Mindanao Island in the Philippines. Total cost of the project is to be more than $23 million.

Engineering, construction, and initial operation services will be performed by the Foster-Wheeler Corp., while E. W. Bliss Co. will furnish rolling and fabricating equipment for converting powder into strip. Also scheduled to participate are Chemetals Corp. and Sherritt-Gordon Mines which own and license the chemical reduction techniques.

Before actual construction of the Philippine plant gets underway, Chemetals and Sherritt–Gordon will run a substantial tonnage of Marinduque concentrates through Sherritt-Gordon's facilities. In this way, selected Marinduque personnel will be trained and the sizing of certain equipment and machinery for the new plant can be verified.

On an annual basis, the proposed plant will produce 14,400 tons of copper and copper products, 4500 tons of zinc, and almost 88,000 tons of ammonium sulfate, which is needed in the Philippines as a fertilizer for sugar and rice crops.

The process

The new copper plant in most respects will be identical to Sherritt–Gordon's Fort Saskatchewan plant, although modifications will be required to treat a copper zinc concentrate instead of the Canadian nickel-cobalt-copper concentrate.

The concentrate will first be treated in a continuous leaching operation using ammonia and compressed air at 180°F and 100 psig. A series of 11x45 ft autoclaves will be employed, with extraction efficiencies of 96 pct for the copper and 77 pct for the zinc in the primary circuit. Following liquid: solid separation, excess free ammonia will be removed in a continuous distillation unit. The solution is to be purified in a combined oxidation and hydrolysis operation where the unsaturated sulfur compounds are oxidized and ammonium sulfamate is hydrolyzed; this oxydrolysis is to take place at 475°F and 500 psig with compressed air being used to supply oxygen.

Copper reduction with hydrogen will take place in a series of seven autoclaves at 400°F and a total pressure of 650 psig, of which the partial pressure of hydrogen is to be 400 psi. Zinc will be held in solution by control of the ammonia content.

At a later point zinc is to be recovered as a carbonate by blowing with carbon dioxide in a vertical pressure tank at 100 psi and 115°F. At the new plant, zinc may be produced as an oxide or electrolyzed into zinc metal.

Most of the copper powder will be roll-compacted, sintered, and hot rolled into strip, some of which may be used for the production of welded tubing. Output of copper wire by *traditional* means is also contemplated.

Other installations?

This integrated Ammonia leach-Hydrogen reduction–Compacting process is, as has been pointed out, a combination of a number of different developments by several organizations; hence the process-combination is as yet unnamed, and we would venture, for the purpose of simplicity, to call it the AHC copper process and the AHC nickel process.

Marinduque will be the first AHC copper producer to operate on concentrates. But it is anticipated that others may follow, for the process appears ideally suited for certain specific conditions: a moderate capacity plant on the order of 50-tpd of metal, treating a complex ore, with an assured market for ammonium sulfate as well as copper strip or tubing.

Another realm of application of the AHC copper process is the treatment of complex scrap metal, particularly that containing lead or zinc. Almost 10 years ago Chemical Construction Co. set up a pilot plant in New Jersey to work out treatment details for the ammonia leach–hydrogen reduction process. The work was successful, and resulted in the installation of the small plant of Whitaker Metals Corp. at Kansas City, Mo. It should be noted that there are two differences between this secondary plant and the Philippines primary installation: first a carbonate instead of a sulfate circuit is employed, and secondly copper powder, rather than strip, is the final product.

It appears at this time that the application of the AHC copper process to the treatment of secondary materials may be more widespread than for the treatment of primary materials. It has already been announced that the next two years will see at least two 50-tpd scrap treatment plants built in the US; these will include copper strip in their production programs.

Thus, it can be said that, while the AHC copper process is not likely to mean the dismantling of existing large-scale smelting installations, it certainly does have a place in the industrial picture for treatment of complex secondary and primary materials on a moderate-scale basis.

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Molybdenum Alloy and Process Technology

by R. C. Nelson, Sylvania Electric Products, Inc.

Space Age requirements have exceeded the capabilities of the superalloys and necessitated a rapid development of the refractory metals as the immediate solution to high-temperature (>2000°F) structural applications. Of the refractory metals, molybdenum is in an advantageous position to fulfill the requirements in the 2000° to 3000°F temperature range for the following reasons: 1) molybdenum alloys have exhibited a high strength-to-weight ratio, good tensile strength and stress-rupture properties at elevated temperatures, good thermal conductivity, and a low coefficient of thermal expansion; 2) the technology of molybdenum alloys is in an advanced state of development, and several alloys are commercially available in a variety of wrought forms; and 3) of the refractory metals, molybdenum is in the most abundant supply in the US.

The major drawback to the use of molybdenum for high temperature applications is its catastrophic oxidation rate, which means the metal must be well protected when used in an oxidizing atmosphere. Thus far, no one coating has been developed which is satisfactory for all applications.

Considerable progress has been made in the development and processing of molybdenum alloys since the September 1956 molybdenum symposium, sponsored by the Office of Naval Research. The proceedings of this symposium were published in 1958 in book form as *The Metal Molybdenum*, by the American Society for Metals[1]. The present review will attempt to cover major developmental highlights and Government sponsored programs which have materialized since the 1956 symposium.

ALLOY DEVELOPMENT

Several alloy development programs over the past few years have rapidly advanced the frontier of the useful temperature range for molybdenum-based alloys. The best of these alloys are summarized in Table I, and are classified as commercial, semi-commercial, and developmental. In this classification, a commercial alloy is an alloy which is available from at least one supplier; semi-commercial alloys are those which are available in limited quantities upon request and have reasonably well-documented property data; and developmental alloys have been investigated for a relatively short time, with only limited property data and fabrication history available. In preparing the table, only those alloys were tabulated whose mechanical properties were equal or superior to the commercially-available arc-cast alloys; therefore, no powder metallurgy alloys were included.

Of the commercial alloys numbers two and three (TZM compositions) have the best high-temperature mechanical properties. By comparison, alloy number five (TZC) exhibits relatively little improvement in strength below 2500°F, but it is stronger by 5000 to 10,000 psi in the 2600° to 3000°F range and has a recrystallization temperature which is 250°F higher than obtainable by the TZM composition. Alloy seven, which is a developmental version of the TZM alloy having a higher carbon content, is 5000 to 10,000 psi stronger in the 1000° to 2400°F range.

Alloy eight, the outstanding developmental alloy, has excellent high-temperature properties. It has the highest recrystallized tensile strength, the highest stress-rupture values, and the highest recrystallization temperature recorded for a molybdenum-based alloy. Alloy 10 exhibited the highest stress-relieved tensile strength at 2400°F, and Alloy 12 exhibited high room-temperature and 1800°F tensile strength.

Unfortunately, in these alloys hot strength and fabricability are inversely related, and the developmental work on high-temperature alloys

Table I. Mechanical Properties of Molybdenum-Base Alloys

No.	Nominal Composition Mo + Wt Pct				As-Cast Hardness, DPH		Tensile 70°F, KSI		Tensile 2400°F, KSI		100-Hr Stress-Rupture, KSI			Recrystallization Temp, °F
	Ti	Zr	W	C	2000°F	3000°F	SR[a]	R[b]	SR[a]	R[b]	Temp, °F	SR[a]	R[b]	
Commercial														
1	0.5	—	—	0.02-0.05	63	20	114-128	58-74	20.0	17.0	2400	9.9	—	—
											2000	34.0	21.0	2450
2	0.5	0.08	—	0.02	82	38	120-130	78-80	53.9	23.4	2000	52.0	30.0	2600
3	0.5	0.1	—	0.02	—	—	141-153	—	—	—	—	—	—	2650
4	—	—	30.0	0.02	70	27	121.5	83.8	—	—	1800	47.0	—	—
Semi-Commercial														
5	1.25	0.15	—	0.15	—	—	120.0	—	—	20.0	2200	34.0	—	2900
6	—	0.5	—	0.02-0.04	104	50	108-118	85.0	36.6-41	23.0	2400	9.9	9.7	2650-2800
Developmental	Cb	Ti	Zr	W	C									
7	—	0.46	0.08	—	0.08	88	46	134.0	85.0	58.2	32.8	2400	—	14.4	2900
8	—	1.27	0.29	—	0.30	130	48	120.0	87.0	60.8	46.0	2400	32.7	26.3	3200
9	—	—	0.52	—	0.30	—	—	120.8	—	46.3	—	2400	16.8	—	2850
10	—	—	0.11	25.1	0.05	109	68	141.3	105.0	73.5	28.5	2400	12.3	11.8	2550
11	—	3.20	—	—	0.50	148	72	135.1	117.8	36.3	29.5	2400	10.3	13.0	3150
12	1.45	—	—	—	0.25	80	35	155.6	102.7	64.4	30.5	2400	12.3	11.8	2600

[a] Stress Relieved
[b] Recrystallized

is presently ahead of processing technology. Recognizing this fact, the US government, through its various agencies has instigated process development contracts on molybdenum alloys using various techniques.

PROCESS DEVELOPMENT

FORGING

Westinghouse holds an Air Materials Command (AMC) contract, which has as its objective the development of an economical process for the closed-die forging of a commercially-available molybdenum alloy.[4] Phase I of this contract (a state-of-the-art survey) has been completed, and the Mo – 0.5 Ti – 0.1 Zr – 0.02 C alloy was chosen, because it is the most forgeable of the commercial alloys, and because a great future potential is envisioned for this alloy system.

EXTRUSION

Allegheny Ludlum Steel Corp. is pursuing an AMC contract to develop a reproducible extrusion process for molybdenum alloys, and to produce tee-shaped extrusions, each of which will fit in a 2 in. diam circle, having a minimum length of 10 ft.[5] The arc-cast Mo – 0.5 Ti – 0.09 Zr – 0.02 C alloy was selected for this program because of its high recrystallization temperature and good creep strength. The compositional limits selected for this alloy are intermediate between the two commercial variations of this alloy, but it is a composition which either producer could make. The second part of this program on the arc-casting and evaluation of extrusion billets is underway.

SHEET

Arc-Cast: Universal-Cyclops Steel Corp. Refractomet div.[7], holds a molybdenum sheet rolling contract from the Bureau of Naval Weapons. The developmental phase of this program is concerned with a detailed study of the variables involved in the rolling of molybdenum alloy sheet ultimately to describe and evaluate a process for the commercial production of wide (36 x 96 in.), high-quality sheet exhibiting optimum properties. Universal-Cyclops also plans to devise and evaluate a process for producing sheet in their inert atmosphere room[8].

There are two arc-cast alloys under evaluation, namely: the Mo – 0.5 Ti – 0.02-0.05 C and the Mo – 0.5 Ti – 0.09 Zr – 0.02 C (TZM). Included in the program is an evaluation of single vs double arc-melting practice on the Mo – 0.5 Ti alloy. The second melt produced a 12-in. diam weighing over 2000 lb. Initial process variations are now being studied; these include melting practices, and the extrusion of billets from ingots to rounds and sheet bars. The In Fab room is being readied for use. A drop-weight test rig has been designed and constructed to study the impact upset behavior of slugs machined from the as-cast ingots.

Powder Metallurgy: Sylvania has undertaken a Bureau of Naval Weapons contract on developing molybdenum alloy sheet by powder metallurgy techniques.[9] The objective of the developmental phase is to develop a powder metallurgy alloy which can be fabricated as sheet having properties comparable to those of the commercially-available arc-cast alloys. Standard powder metallurgy techniques have been employed to produce a series of alloys based on dispersion hardening and solid solution strengthening mechanisms. In addition, an attempt was made to duplicate the arc-cast alloys by powder metallurgy.

Of the alloys produced to date, none of the dispersion hardened alloys has equaled the properties of the arc-cast alloys. Good results were obtained from the Mo – 30W alloy which has properties almost equivalent to the arc-cast Mo – 0.5 Ti alloy. A modification of one of the arc-cast alloy compositions (Mo – 25W – 0.11 ZrO_2 – 0.05 C) looks promising on the basis of recrystallization temperature and high temperature properties are being determined. Thus far, the outstanding development in this program has been the ductility of the alloy sheet as measured by the wide bend test. The ductile-brittle transition temperature for the Mo – 30W alloy is approx −75°C (4T bend), and for unalloyed 40 mil sheet ranges from −100° to −150°C, depending on the purity of the starting material.

A corollary program is underway at General Telephone and Electronics Laboratories Inc. to determine the feasibility of producing sheet by the direct rolling of molybdenum powders.[9] The feasibility of such an approach has been demonstrated and the powder characteristics, sintering, annealing, and rolling temperatures have been defined. The unalloyed sheet produced by this technique is comparable in quality to sheet produced by the conventional powder metallurgy approach. It remains only to establish the reproducibility of sheet produced by this technique. The technique has produced molybdenum sheet 6 in. wide x 0.010 in. thick by a batch process. The apparent limitations in this study were due to equipment, for the thickest slab which could be compacted between the rolls was 0.040 in.; therefore, the possibilities of upscaling the technique to produce wide and thicker sheet are good. As is, the process offers a good approach for the production of thin strip. Utilization of this technique to produce alloy sheet depends upon the powder metallurgy alloy developed under the Sylvania contract. This program is essentially completed, and a final report is being prepared.

MAB Panel: A Refractory Metals Sheet Rolling Panel, a counterpart of the Titanium Sheet Rolling Panel, has been formed to monitor the various sheet rolling contracts on the refractory metals. Both of the above molybdenum sheet rolling contracts are reviewed periodically by this panel, which in turn makes recommendations on program modifications for the benefit of the contractors and the contracting agency. The panel has six subgroups to review developments in various fields of interest, and devise methods for standardization where necessary. The subpanels are actively working on: alloy requirements and selection, analysis methods, coatings, standardization of test methods, joining, and quality specifications.

The alloy selection and requirements group has proposed a series of target properties for alloys of molybdenum, columbium, tantalum, and tungsten. These target properties are to serve as a guide for selecting future alloys for Government programs, and the panel realizes that any one candidate may not meet all of these targets. Some of the target properties for the selection of molybdenum alloys include: tensile and yield strength and elongation at room and elevated temperatures. For example, at temperatures in the 2000° to 2400°F range, fabricable molybdenum alloys should have ultimate tensile strengths on the order of 50 to 75 ksi, and have yield strengths of 35 to 60 ksi; and high-strength alloys in the temperature range of 2400° to 3000°F should have tensile strengths of 25 to 75 ksi with yield strengths of 15 to 60 ksi, depending upon their condition. In addition, other targets are provided for creep-rupture properties, recrystallization times and temperatures, notch sensitivity properties, transition temperatures, and bend ductility properties. Target properties are supplied for both fabricable and high-strength molybdenum alloys for both optimum and completely recrystallized conditions. For further information concerning the activities of the MAB Panel, readers are directed to the *Progress Report of the Refactory Metals Sheet Rolling Panel of the Materials Advisory Board*, MAB-161-M(1-4).

This subpanel has established a series of ground rules to be followed to insure that the alloy candidates have demonstrated potential producibility. Therefore, the following minimum billet or sheet sizes must be produced in order to qualify: 1) pilot development status ingots or billets must have 2 in. min section, and sheet requirements are 6 x 20-in. min; and 2) for preproduction development status ingots or billets must have 6-in. min section, and

sheet requirements are 18 x 48-in. min. Sheet gages may be 0.010 to 0.100 in. Although disclosure of composition is not mandatory during presentation of an alloy candidate, disclosure must be made, if the alloy is selected. The above sizes hold for molybdenum alloy candidates, but there are preproduction size variations to cover electron beam melted tantalum or columbium and tungsten sheet.

CASTING

The U. S. Bureau of Mines, Albany, Ore. has successfully arc-cast molybdenum into static and rotating molds employing the conventional equipment used for casting titanium and zirconium[10]. Static casting will require further research before castings with an acceptable surface appearance and internal soundness can be produced. The centrifugal castings produced, however, were dense, sound, and had physical and mechanical properties equal to unworked shapes produced by powder metallurgy or to sections taken from arc-cast ingots. For further information the reader is referred to the Report of Investigations, which describes the arc-casting and pouring techniques, discusses the graphitic mold materials, and reviews the properties of the castings.

UNCONVENTIONAL TECHNIQUES

Kroll reduction: The Armour Research Foundation has just completed a Bureau of Naval Weapons contract and demonstrated the feasibility of producing alloyed molybdenum by the Kroll process using a co-reduction of mixed chlorides[11]. Alloys of molybdenum with titanium and with titanium and carbon have been successfully produced by this method. Since the alloying reaction takes place in the vapor phase, the resultant alloy is produced in the form of a powder and not as a sponge. Extrusion equipment was modified to obtain extrusion data on the sintered (70 pct dense) billets. Data indicate the operational characteristics necessary for the direct extrusion of molybdenum alloy powder.

Bomb reduction and EBM melting: Wah Chang Corp., Albany, Ore., is pursuing a Bureau of Naval Weapons contract on the reduction and consolidation of superior-quality molybdenum alloys[12]. Wah Chang's objective is to obtain good ductile molybdenum-base metal, and, by preparing the metal in various ways, gain an understanding of the influence of various impurities. One aspect of their approach is to determine the effect of hydrogen on the properties of molybdenum. Hydrogen reduction and a calcium bomb reduction of oxides, coupled with electron-beam melting are the reduction and consolidation methods under consideration, the material will be processed to sheet for evaluation.

Thermal dissociation: The Climax Molybdenum Co. of Michigan has been pursuing a Bureau of Naval Ordnance research contract on new processes for producing ductile molybdenum[13]. The particular approach used by Climax is the thermal dissociation of molybdenum disulfide. In order to effectively work on this approach, Climax had to design and construct a special furnace, and this is in the final stages of design.

Electrolysis of a fused bath: The US Bureau of Mines, Reno, has had an intensive program underway on the electrowinning of tungsten and associated molybdenum from scheelite[14]. In their approach, the Bureau has been mainly concerned with developing a technique for producing high-purity tungsten from Western scheelite ores, which are generally contaminated with molybdenum. During the investigation of the fused-bath electrolysis, the separation of molybdenum and tungsten under controlled conditions was found to be feasible. Consequently, this offers the possibility of another by-product source of molybdenum.

Tin reduction of MoS_2: For the past two years, the Oregon Metallurgical Corp. has been pursuing the upscaling of the Poole-Nachtman technique to produce 25 to 50 lb ingots of molybdenum by the tin reduction of molybdenum disulfide[15]. The metal produced is to be evaluated for arc-melting, forging and casting evaluation fabrication studies.

JOINING

An excellent summary on the welding and brazing of molybdenum was issued by the Defense Metals Information Center (DMIC) of Battelle Memorial Institute[16]. The reader is referred to this report for detailed information on the metallurgical considerations involved, the testing of joints; cleaning; fusion, resistance, and solid-state welding; and brazing.

COATING

The Defense Metals Information Center of Battelle Memorial Institute has also issued a summary report on coatings for oxidation protection at elevated temperatures[17]. For detailed information on coatings, the reader is referred to this report which summarizes electrodeposited, flame-sprayed, vapor-deposited, clad, enameled, and liquid-phase diffused coatings.

PROPERTIES

High temperature test data is becoming available on molybdenum and molybdenum alloys. Work was performed at the National Aeronautics and Space Administration Lewis Research Center, on the tensile properties of arc-cast molybdenum and molybdenum alloys from 2500° to 3700°F[18]. The Los Alamos Scientific Lab. has determined the creep-rupture behavior of powder metallurgy molybdenum rod in the temperature range of 1600° to 2500°C at stresses up to 9000 psi and times up to one month.[19] In addition, there is the DMIC summary report on the properties of molybdenum and the Mo – 0.5 Ti alloy[5].

SUMMARY

Molybdenum technology showed large gains in the 1956 Symposium, and subsequent work should give us within the next year or two, well-documented process histories and property data. Meanwhile, the alloy development phase is far ahead of the processing of the alloys and should further expand the useful temperature range of molybdenum alloys.

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BAR AND ALLIED PRODUCTS

Third Mechanical Working Conference

Bar and Allied Products was the theme for the third conference sponsored by the Iron and Steel Division's Mechanical Working Committee in conjunction with AIME's local Pittsburgh Section. On January 18, 1961, Pittsburgh's Penn-Sheraton Hotel was the site of the all-day conference which attracted some 267 metalworking men. In contrast to the committee's two previous conferences, bar and allied products were emphasized rather than flat rolled products.

The morning session was concerned with the Surface Preparation and Rolling of Primary Products. C. F. Schrader, Inland Steel Co., Chairman of The Mechanical Working Conference welcomed the registrants and introduced R. S. Gentz of Inland Steel Co., and J. G. Parr of the University of Alberta who served as co-chairmen of the session.

V. E. Elliott and J. V. Florchak of U.S. Steel Corp. presented a paper on *Control of Bar Mill Quality* which enumerated the effects of chemistry, melting, primary rolling, bar rolling, and inspection on surface quality. The authors described the extensive program of indexing the quality of bars from various billets with regard to open-hearth practice, nozzle size, finishing temperature, pickling, double re-rolling practices, and bar mill heating practices. They also pointed out that feedback of information from the customer could play an important role in attaining higher quality bar products.

Timken's Approach to Bloom and Billet Conditioning, presented by A. B. Glossbrenner of Timken Roller Bearing Co., described the company's scarfing, cleaning, and inspection operations. At Timken, all billets and blooms are manually skinned in a 100-pct scarfing operation. The company feels that this practice not only reduces the number of rejects in the final product but also aids in decreasing the amount of inspection necessary throughout the rolling process.

T. G. Bradbury of The Steel Co. of Canada Ltd. discussed *Billet and Bar Quality as Affected by Double Conversion and Direct Rolling Practices at The Steel Co. of Canada Ltd.* The paper described the company's bloom mill double-conversion method and compared the results with products of direct rolling. The double-conversion method consists of reducing the ingot to a bloom, followed by scarfing, reheating, and rolling to a billet. The method was found to reduce the required scarfing, the amount and time for chipping, and the inspection time when compared with the direct rolling process. In addition, the surface of the products of the double conversion method was found to be superior to that of the direct rolled products.

Effect of Composition in Causing Breaks During Blooming, presented by J. V. Russell and R. Gaydos of Republic Steel Corp., illustrated the effects of sulfur and aluminum during the blooming operation. The authors pointed out that sulfide films often led to ingot cracking, thus causing surface imperfections on the blooms. It was also found that sulfur decreases hot ductility while higher rolling temperatures tend to improve this property. Aluminum, in the form of aluminum nitride, can also cause hot shortness in the rolling operation.

At the luncheon, J. J. Golden, Chairman of the Iron and Steel Division of The Metallurgical Society, delighted at the fine turnout for the conference, pointed out that many of persons in attendance were non-AIME members. He also noted that the conference is the only one of its type held on the North American continent. Guest speaker at the luncheon was R. B. Pease, executive director of The Pittsburgh Redevelopment Authority, who explained what has happened to Pittsburgh in his talk *Pittsburgh Renaissance*. Mr. Pease related that Pittsburgh was on the verge of dying at the end of World War II because of two specific problems—smoke and floods. He illustrated how local industry and business supported an over $197-million program to overcome these problems, and how the local government is working in conjunction with private industry and the Federal government in alleviating present and future problems facing the city. Mr. Pease also warned that other large cities will be facing many civic problems in the near future and that now is the time to formulate plans to overcome these problems. Certainly anyone familiar with Pittsburgh some 15 years ago will have to agree that it definitely is undergoing a modern renaissance.

New Developments in Processing and Testing provided the basis for the afternoon session. M. D. Stone of United Engineering Co., and J. K. Seyler of Jones & Laughlin Steel Corp. served as co-chairmen of the session. Andrew Wilson of United Engineering Co. presented *Rod, Bar and Light Section Mills* which provided a survey of the various mills in operation and indicated some of the possible features to be found in future mills. Significant was the prediction that continuously-cast billets will be on the scene in the future. An extra added treat was the showing of a motion picture of Jones & Laughlin's *Rendleman Rod Mill*, considered by many to be one of the finest rod mills in the world.

Extrusion of Steel, presented by D. A. Edgecombe of Babcock & Wilcox Co., discussed extrusion theory and pointed out the advantages of this fabrication method. An article based on this paper can be found on p. 211 of this issue of the JOURNAL OF METALS.

R. N. Edmondson of Inland Steel Co. discussed *Ultrasonic Inspection for Internal Soundness of Semi-Finished Products*. The author described the mechanism of ultrasonic testing and presented some of the factors involved in setting-up and calibrating the equipment. Among factors effecting the testing are surface roughness, heavy scale formation, chemical composition, and grain size. The company has found that this type of testing has eliminated macroetching techniques and has proved to be more sensitive and versatile than the former method.

Use of Magnetic Particle Testing for Surface Defects on Bars and Allied Products by A. Debb of Youngstown Sheet & Tube Co. provided a review of the theoretical aspects of magnetic particle testing and pointed out that effective use of the inspection method could enhance the properties of bar and mill products.

Plans are being made for another conference on flat rolled products to be held in Chicago on January 24, 1962.

Chairman C. F. Schrader and his Mechanical Working Committee should be congratulated for presenting a most interesting and informative conference. The proceedings will be published by Interscience Publishers, Inc., and will be available later this year.

EJF

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NEWS OF YOUR PROFESSION

Herty Memorial Award Is Established by Open Hearth Committee

The National Open Hearth Steel Committee of AIME has established the Herty Memorial Award which will be given to the author of the best paper to be published in the Open Hearth Proceedings each year.

The award honors the late Charles H. Herty, Jr., scientist, engineer, and steel executive, who died in 1952. According to the NOHC Resolution, Dr. Herty, "son of an illustrious scientist, spent his lifetime in reducing scientific principles to practice in the steel plant. His unique ability to translate scientific terms into the language of the open hearth first helper, not only inspired other scientists to follow suit, but also greatly encouraged steel operators to attempt many changes in steel plant practice which would have otherwise been regarded as foolhardy or impractical.

"During his period as director of the research program on the *Physical Chemistry of Steelmaking* at the US Bureau of Mines from 1926 to 1932, steel refining began to disappear as an *art* and emerge as a science, and he is credited with a major role in this transformation."

The award was established "because of Herty's genius in discovering the underlying principles in phenomena involved in the art of steelmaking and his ability to reduce these to routine open hearth practice.

The recipient will be selected by a committee appointed by the chairman of the NOHC. Special consideration will be given to papers in which the author has reduced some scientific principle to practical steel plant use, but this will not necessarily govern the selection.

The award, in the form of a scroll and a $100 government bond, will be presented at the NOHC Conference following the publication of the Proceedings each year, beginning with the 1961 Conference (award to be presented at the 1962 Conference).

The National Open Hearth Steel Committee had earlier honored Mr.

(*Continued on page 235*)

Fellowships Honor Three Past EMD Chairmen

H. H. KELLOGG

A. W. SCHLECHTEN

REINHARDT SCHUHMANN

Graduate fellowships in nonferrous extractive metallurgy have been established at three universities honoring three past chairmen of The Metallurgical Society's Extractive Metallurgy Division. The grants, each totaling about $4000 per year, were established at Columbia University, Purdue University, and the University of Missouri School of Mines and Metallurgy by the American Metal Climax Foundation, Inc., of New York.

In making the grants, the Foundation expressed its desire not only to contribute to the advancement of education in metallurgy, but also to recognize thereby the outstanding contributions to the science of metallurgy already made by distinguished faculty members at the designated universities. The honored individuals, are Herbert H. Kellogg (EMD Chairman 1957-58), professor of mineral engineering at Columbia University, and well known for his work in the thermodynamics of metallurgical reactions; Reinhardt Schuhmann (EMD Chairman 1959-60), professor of metallurgical engineering and chairman of the div. at Purdue, noted for his research in the physical chemistry of flotation and extractive metallurgy; and Albert W. Schlechten (EMD Chairman 1955-56), chairman of the metallurgical engineering dept. at the Missouri School of Mines and Metallurgy who has been particularly active in the advancement of vacuum metallurgy and the metallurgy of titanium and zirconium.

Selection of fellowship candidates will be at the discretion of the respective schools, and with the exception that the fellowship studies are expected to be generally in the field of non-ferrous extractive metallurgy, the grants are entirely unrestricted and completely in the control of the recipient schools.

Engineers' Salaries Rose 5% Per Year Since 1958

Engineers' salary levels rose approximately 5 pct per year between 1958 and 1960 according to a survey conducted by the Engineering Manpower Commission (EMC) of Engineers Joint Council (EJC). The overall median annual salary now stands at $9600. Seven years ago (1953), the first in this series of surveys found the median salary for engineers at $6500. These findings were made public by EMC in the fourth of a series of surveys entitled, *Professional Income of Engineers—1960* which covers approximately 200,000 engineering graduates in industry, education, and government.

There is a marked difference between engineering salaries in industry, government, and education, with highest level in industry, followed by education and government. Of particular note is the 14.3 pct increase in the total professional income of engineering teachers between 1958 and 1960.

Copies of the report are available from the Engineering Manpower Commission, 29 West 39 Street, New York 18, N.Y., at $3.00 a copy—slightly lower in bulk.

36 Technical Papers Planned For Conference On Agglomeration

The First International Symposium on Agglomeration, which will be held in Philadelphia on April 12-14, is a specially arranged all-AIME function; it is sponsored by the three societies of AIME.

The programming of the symposium is directed toward the basic process mechanism common to all agglomerating processes. It is, therefore, more basic than applied. The program has papers dealing with agglomeration as it is understood and practiced in the fields of ceramics, powder metallurgy, cement, lead, zinc, carbonaceous materials, and ferrous and nonferrous metals and minerals. The agglomeration processes under consideration in the program include briquetting, pressure compacting, sintering, nodulizing, pelletizing and various powder metallurgy techniques, such as slip casting and vibratory compacting. The overall theme of the conference is one of cross-pollination of ideas, techniques, and thinking.

A total of 71 authors offered papers to the symposium. About 25 papers were eliminated on the basis of abstracts received.

In some cases, too many papers were offered from a given country or organization; some were rejected to permit acceptance of papers from other sources or pertaining to other industries. Forty-five authors submitted completed manuscripts for final program selection. From these, 36 papers were chosen, 35 to be orally presented and discussed. There will be 18 papers from foreign authors, and 18 from US authors; 32 papers will be from research and development activities, and four will be from engineering firms. Thirty-five papers will be preprinted, presented, discussed and published. There will be five non-simultaneous sessions and two simultaneous sessions.

British Metals Group Plans 1961 Conference On Beryllium

The Institute of Metals (Great Britain) will hold a three-day conference on *The Metallurgy of Beryllium* in London October 16-18, 1961. It is planned to publish and discuss previously unpublished original work on beryllium, covering metal fabrication, physical and mechanical properties, and metal physics—in fact, all phases of the metallurgy of beryllium except extraction processes. The conference will be organized by the Institute's Nuclear Energy Committee.

Metallurgical Society Bylaw Revision

At a meeting of the Board of Directors of The Metallurgical Society in Philadelphia on October 19, it was noted that the Finance Committee is hampered in its work by having only three members. This means that if two members should be absent, the Finance Committee is unable to function. The following suggested revision of Article VII, Section 4, was presented:

The President shall appoint at the Annual Meeting of AIME a Finance Committee consisting of the Treasurer and three (3) members of The Metallurgical Society.

A motion was made, seconded, and carried to approve the revision in bylaws of Article VII, Section 4. The motion has been approved by the Institute's Executive Committee.

NE Regional Conference Scheduled May 18-19 In Schenectady, N. Y.

The fifteenth New England Regional Conference, sponsored by the Boston, Connecticut, and Hudson-Mohawk sections of AIME, will be held May 18-19 at the General Electric Research Laboratory in Schenectady, N. Y.

The title of the conference will be *The Basic Metals Industry—Technical and Economic Perspectives*. It will feature three technical sessions on *How it Grew, What It Is*, and *Where It's Going*. The three major talks in each session will center on the aluminum, copper, and steel industries. The first session will deal with the origin and development of each industry, both technically and economically. The second session will be concerned with each industry today, as its operations relate to costs, the state of technology, and competition with other materials and foreign producers. The third session will look at the future of each industry and how it will reflect technological and economic change.

Panel discussions will be held after the second and third sessions, and the afternoon of May 19 will be devoted to a visit to an industry in the Schenectady area.

The program and details of registration will appear in the April issue of JOURNAL OF METALS, or can be obtained by writing to David A. Thomas, Publicity Chairman, Room 16-502, Massachusetts Institute of Technology, Cambridge 39, Mass.

Pacific Northwest Conference Scheduled Apr. 13-15 in Spokane

The Pacific Northwest Minerals Conference, which will be held April 13-15 at the Davenport Hotel in Spokane, Wash., will feature 11 technical sessions. A joint effort of the Columbia section of AIME and the American Society for Metals, the conference will have seven sessions sponsored by AIME and four sponsored by ASM.

The AIME sessions will include two on mining; it is tentatively planned that one will be devoted to sand fill and the other to the use of concrete underground. There will also be two sessions on geology, and one each on industrial minerals, mineral beneficiation, and geophysics.

ASM will sponsor two sessions on primary metal working and two on secondary metalworking. All technical sessions will be held at the Davenport Hotel on April 13 and 14 and will be followed by field trips on Saturday, April 15.

Research Management Will Be Subject Of Meeting May 17-19

The conference on Management of Materials Research which will be held at the Arden House in Harriman, N. Y., May 17-19 will be the first in a new series of activities. Sponsored by The Metallurgical Society's Management of Materials Research and Engineering Group, the conference is designed primarily to appeal to members who are now, or expect to be, concerned with the *management* of materials research and engineering, rather than materials research and engineering as such.

All registrants will be housed in or near the Arden House in Harriman. The number of registrants will be limited by the available housing facilities.

Registration fees for the conference, payable at the time of registration, are: AIME members, $200; non-members $250. These fees include admission to the conference, room and board while at Arden House, copies of case studies and other conference materials, and a copy of the bound proceedings.

Persons desiring to register for the conference must do so on the form provided for that purpose; full payment of the registration fee must accompany each form. Registration forms are being mailed to Metallurgical Society members during March. Forms may also be obtained from D. C. Johnston, The Metallurgical Society of AIME, 29 West 39th Street, New York 18, N. Y.

AROUND THE SECTIONS

The Annual Meeting of the Arizona section, AIME, was held in Tucson December 5. Pictured above are AIME members who attended a conference with President Richard A. Harvill, University of Arizona. Seated are (l to r), A. P. Morris, general manager, Ray Mines div., Kennecott Copper Corp., and immediate past-chairman, Arizona section AIME, Hayden, Arizona. B. R Coil, vice president and general manager, Miami Copper Co., and second vice-chairman, Arizona section AIME, Miami, Arizona. T. A. Snedden, general manager, Southwestern div., American Smelting & Refining Co., and first vice-chairman, Arizona section AIME, Tucson, Arizona. Ronald R. McNaughton, manager, Metallurgical div., Consolidated Mining & Smelting Co. of Canada, Ltd., and President of AIME, Trail, British Columbia. Richard A. Harvill, president, University of Arizona, Tucson, Arizona. Walter C. Lawson, vice president and general manager, Phelps Dodge Corp., and chairman, Arizona section AIME, Douglas, Arizona. E. O. Kirkendall, Secretary, AIME, New York. C. P. Donohoe, vice president and general manager, Cananea Consolidated Copper Corp., S.A., Cananea, Sonora, Mexico. H. Carroll Weed, vice president and general manager, Inspiration Consolidated Copper Co., Inspiration, Arizona. Standing (l to r), J. D. Forrester, Dean, College of Mines and Director, Arizona Bureau of Mines, University of Arizona, Tucson, Arizona. D. F. McElhattan, district manager, Mines Safety Appliances Co., Salt Lake City, Utah. J. B. Pullen, assistant general manager, Phelps Dodge Corp., Douglas, Arizona. Clifford J. Hicks, Western Field Secretary AIME, Salt Lake City, Utah. P. S. Geshell, assistant director labor relations, Phelps Dodge Corp., and Secretary-Treasurer, Arizona section AIME, Douglas, Arizona. Donald F. Wright, senior in mining engineering, College of Mines, and president, student chapter AIME, University of Arizona, Tucson, Arizona. George E. Atwood, vice president and general manager, Duval Sulphur and Potash Co., Tucson, Arizona. T. G. Chapman, Dean Emeritus, College of Mines, University of Arizona, Tucson, Arizona.

San Francisco section met January 11 at the Engineers' Club. The annual change of officers was made, and a report on the section's yearly operation was made. New officers and committee chairmen were introduced. *Outlook for and Practical Use of Geochemical Prospecting* was discussed by Dr. Herbert Hawkes of the University of California. The sections next meeting will be the annual dinner dance with the ladies auxiliary of AIME. It will be held in the Gold Room of the Palace Hotel on March 18.

Detroit section, AIME, and the Detroit NOHC held a joint meeting February 20 at the Rackham Building in Detroit. John F. Elliott, associate professor at Massachusetts Institute of Technology, spoke on *Slag-Metal Reactions.*

Morenci sub-section (Arizona) met December 13 at the Longfellow Inn. and elected officers for 1961. New chairman of the sub-section is J. B. Stanley. Others elected were, Fred M. Winkler, vice chairman and program chairman; W. A. Griffith, secretary and treasurer; and C. Sorvisto, membership and nominations chairman. Following custom, this was also Ladies' Night. Westinghouse presented the program for the evening.

Western section of the AIME Steel Committee met January 18 at the Rodger Young Auditorium in Los Angeles. The speaker for the evening was Hale Hursen, assistant vice president, engineering and research, Griffin Wheel Co. of Chicago. Mr. Hursen discussed *Pressure Pouring in Graphite Molds,* and showed a film.

Southwestern Section, NOHC, held a one-day meeting at Hotel Lennox on Friday, February 10. There were morning and afternoon technical sessions which included papers on *New Desulphurization Methods* by S. L. Fredericks, chief metallurgist, American Steel Foundries; *Ingot Mold and Stool Manufacturing* by R. C. Harrell, superintendent of foundries, Lone Star Steel Co.; and a *Symposium on Ladle Refractories* with all companies participating.

Also on the program was *Experience with Checker Practice and Design,* by R. G. Phelps, manager, steel production, Inland Steel Co.; *Quantitative Analysis of Segregation within Rimmed Steel Ingots* by Louis Schoff, open hearth metallurgist, Keystone Steel & Wire Co.; *Developments in Basic Roof Life and Construction* by George Warnock, assistant to the div. superintendent, steel producing div., U.S. Steel Corp., (Gary Works). The technical sessions concluded with all companies participating in a Symposium on Safety.

The Fellowship Dinner on Friday evening featured a talk by Kenneth McFarland, who during the past decade has been voted America's Foremost Public Speaker in a nation-wide poll conducted by the U.S. Chamber of Commerce. Dr. McFarland is educational consultant for General Motors Corp., and the American Trucking Assn.

Pittsburgh section's Institute of Medals Division met January 19 to hear an address by Dr. Volker Weiss, associate professor of metallurgy at Syracuse University. Dr. Weiss discussed *Current Views, Concepts, and Theory of Fracture, Crack Initiation and Crack Propagation.* He stated that the two main approaches to the brittle fracture problems are the Griffith-Irwin fracture mechanics approach and a fracture concept based on Neuber's theory of stress concentrations. The stress gradient at the root of the notch and the section size affect, which appears to be intimately related to the stress gradient, were also considered. In a comparison of the Griffith-Irwin and the Neuber concept, it was shown that the two concepts yield identical results or extremely sharp and shallow notches. The Neuber concept has the advantage that it is not only applicable to sharp notches, but to mild stress concentrations as well. Finally, the present state of knowledge on crack propagation was reviewed.

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CONFERENCE ON HIGH TEMPERATURE MATERIALS SCHEDULED APRIL 26-27 IN CLEVELAND

A technical conference on High Temperature Materials will be held at the Pick-Carter Hotel in Cleveland, Ohio, April 26-27. Sponsored by the Cleveland Section, AIME, and The Metallurgical Society, the conference will emphasize materials for use at temperatures above 1600°F in aircraft, missiles, and nuclear reactors, and will be of interest to engineers and scientists working in these fields.

The demands of high operating temperatures make the design and development of new materials imperative. The conference will feature discussions of the classes of materials that are attractive for these applications, their properties, and the effects of methods of preparation and evaluation.

The Fellowship Hour and Dinner will be held Wednesday evening, April 26, in the Rainbow Room of the Pick-Carter Hotel. Persons planning to attend the dinner are urged to buy tickets when registering. Ticket sales will end at 12 noon on the day of the dinner.

Featured speaker at the dinner will be George M. Low, chief, Manned Space Flight, National Aeronautics and Space Administration Headquarters, who will discuss *Manned Flight in Space*. Mr. Low will describe *Project Mercury*, the first step in the United States' manned space flight program. The goals of this project are to put a manned satellite into orbit more than 100 miles above the earth's surface, let it circle the earth three times, and then bring it back safely. Mr. Low will discuss the development of the Mercury space craft, the results of recent flight tests, and plans for the astronaut's first flight. The talk will be illustrated with slides and a motion picture in color.

George M. Low

In addition, Mr. Low will describe briefly the next planned step, *Project Apollo*, which ultimately will place man in a flight around the moon.

The program has been arranged to provide ample time for oral discussions of all topics. Delegates are invited to ask questions or to contribute to the sessions by giving others in attendance the benefit of their experience.

The Registration desk on the North Mezzanine of the Pick-Carter Hotel will be open on Wednesday, April 26 from 8 am to 5 pm, and on Thursday from 8 am to 12 noon. Registration fees are $15 for AIME members and $20 for non-members. This includes a copy of bound proceedings which will be mailed following the conference. The fee for non-member students is $1. There is no fee for AIME student members. Advance registration forms are available from D. J. Berger, Clevite Research Center, 540 East 105 Street, Cleveland 8, Ohio.

Change of Address

▼To be sure that you receive your publications and correspondence promptly, please fill in the form below and send it to **The Metallurgical Society of AIME, 29 W. 39th St., New York 18, N.Y.**

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Personals Form

▼**Personals:** Please list below your former company and title and your new title and company (or new work) for use in JOURNAL OF METALS. (Copy deadline for personals items is six weeks before date of issue.)

Former Company _____

Former Title _____ Length of Time There _____

New Company _____

New Company Address _____ Date of Change _____

New Title _____

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PROPOSAL FOR AIME MEMBERSHIP

I consider the following person to be qualified for membership and request that a membership kit be mailed to him:

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TECHNICAL CONFERENCE ON

HIGH-TEMPERATURE MATERIALS

Sponsored by Cleveland Section, AIME
in cooperation with Refractory Metals Committee
High Temperature Alloys Committee
Institute of Metals Division
The Metallurgical Society of AIME

Pick-Carter Hotel, Cleveland, Ohio • April 26-27, 1961

Wednesday AM, April 26

Breakfast for Authors and Chairmen

8:30 am — Aviation Room

Registration

8:00 am to 5:00 pm — North Mezzanine

Conference Opening

9:45 am — Grand Ballroom

Welcoming Remarks: H. P. Munger, General Chairman, and A. D. Schwope, Section Chairman

Requirements for High Temperature Materials

Moderator:
N. E. Promisel, Bureau of Naval Weapons

Air Breathing Devices:
A. Levy, Hughes Tool Co.

Chemical Rockets:
R. A. Perkins, Lockheed Aircraft Corp.

Space Vehicles:
G. M. Ault, Lewis Research Center, NASA

Hypersonic Re-entry Vehicles:
W. H. Dukes, Bell Aerosystems Co.

Nuclear Applications:
A. E. Focke, ANPD, General Electric Co.

Wednesday PM, April 26

Tungsten, Tantalum and Their Alloys

(Simultaneous Session)

2:00 pm — Grand Ballroom

Chairmen:
A. B. Michael, Fansteel Metallurgical Corp.
J. W. Pugh, General Electric Co.

Status and Future of Tantalum, Tungsten and Their Alloys:
H. R. Ogden and *D. J. Maykuth*, Battelle Memorial Institute

Bold type indicates summary paper.
Roman type indicates research results.

Mechanical Properties of Arc Melted Tungsten and Some Tungsten Alloys:
F. A. Foyle, Lewis Research Center, NASA

Tungsten-Rare Earth Alloys:
C. Thomas, G. Asai, and H. Kato, U.S. Bureau of Mines

Effect of Surface Condition on the Ductility of Tungsten:
J. R. Stephens, Lewis Research Center, NASA

Properties and Fabrication of Tantalum-base Alloys:
A. L. Field, Jr., R. L. Ammon, A. I. Lewis, and *L. S. Richardson*, Westinghouse Electric Corp.

Physical Properties and Fabrication Techniques for Tantalum-base Alloys:
M. L. Torti, National Research Corp.

High Temperature Oxidation Behavior of Complex Tantalum Alloys:
W. D. Klopp, D. J. Maykuth, and *H. R. Ogden*, Battelle Memorial Institute

Cobalt and Nickel Base Alloys

(Simultaneous Session)

2:00 pm — Lorenzo Carter Room

Co-Chairmen:
J. W. Freeman, University of Michigan
G. A. Fritzlen, Haynes Stellite Co.

Status and Future of Cobalt and Nickel Base Alloys:
W. H. Sharp, Pratt & Whitney Aircraft

Nickel Base Alloys for the 1960's:
C. S. Freer, R. A. Woodall, and *S. Abkowitz*, Kelsey-Hayes Co.

A New Series of High Temperature Nickel-base Alloys:
J. C. Freche, W. J. Waters, and *T. J. Riley*, Lewis Research Center, NASA

Effect of Heat Treatment on a Cast Age-Hardenable Ni-Cr Alloy:
C. G. Bieber and R. F. Decker, International Nickel Co.

Effect of Phase Changes on the Workability and Mechanical Properties of Udimet 700:
J. Quigg, Thompson Ramo Wooldridge Inc.

Effect of Metallurgical Factors on Creep-rupture of Alloys at Very High Temperatures:
M. Korchynsky, Union Carbide Metals Co.

Effect of Alloying on the Properties of Wrought Cobalt:
J. J. Rausch, J. B. McAndrew, and *C. R. Simcoe*, Armour Research Foundation

Wednesday PM April 26, continued

FELLOWSHIP HOUR	6:15 pm
CONFERENCE DINNER	7:00 pm
Wednesday, April 26	Rainbow Room

Welcoming Remarks

Speaker: George M. Low, Chief, Manned Space Flight, NASA

Topic: Manned Flight Into Space

Tickets, priced at $6.00, must be purchased before **12 noon on Wednesday, April 26.**

Thursday AM, April 27

Breakfast for Authors and Chairmen

8:00 am — Aviation Room

Registration

8:00 am to 12 noon — North Mezzanine

Panel on the Processing and Fabrication of Refractory Metals

(Simultaneous Session)

9:00 am — Grand Ballroom

Moderator:
W. A. Johnson, Thompson Ramo Wooldridge Inc.

Consolidation

Powder Metallurgy	*R. C. Nelson*, Sylvania Electric Products, Inc.
Melting	*S. E. Yih*, Wah Chang Corp.
Casting	*R. A. Beall*, U. S. Bureau of Mines

Working

Extrusion	*P. Duletsky*, ARDC, U. S. Air Force
Forging	*A. S. Nemy*, Thompson Ramo Wooldridge Inc.
Rolling to Sheet	*P. C. Rossin*, Universal Cyclops Steel Corp.

Joining *W. Rostoker*, Armour Research Foundation

Molybdenum, Columbium and Their Alloys

(Simultaneous Session)

9:00 am — Lorenzo Carter Room

Chairmen:
E. M. Mahla, E. I. duPont deNemours & Co.
C. Mueller, Universal-Cyclops Steel Corp.

Status and Future of Molybdenum, Columbium and Their Alloys:
L. P. Jahnke, General Electric Co.

Mechanical Properties of Cb-V-Mo and Cb-V-W Alloys:
R. T. Begley, Westinghouse Electric Corp.

Properties of Some Columbium-base Alloys in the Columbium-Tantalum-Tungsten-Zirconium System:
W. O. Gentry and *A. B. Michael*, Fansteel Metallurgical Corp.

Aging Phenomena in Columbium-base Alloys:
D. O. Hobson, Oak Ridge National Laboratory

Development of High Strength Columbium-base Alloys for Reactor Cladding Application:
J. A. DeMastry, F. R. Schober, and *R. F. Dickerson*, Battelle Memorial Institute.

Solution and Aging Reactions in Molybdenum-base Alloys:
W. H. Chang, General Electric Co., and *I. Perlmutter*, Wright Air Development Division

Vanadium Alloys for 1800 to 2200°F Service:
B. R. Rajala and *R. J. Van Thyne*, Armour Research Foundation.

Thursday PM, April 27

Fabrication of Refractory Metals

(Simultaneous Session)

2:00 pm — Grand Ballroom

Chairmen:
W. L. Finlay, Crucible Steel Co.
S. Shelton, Oregon Metallurgical Corp.

Extrusion Studies and Mechanical Property Determination on Several Arc-Cast Molybdenum and Tungsten-base Alloys:
M. Semchyshen and R. Q. Barr, Climax Molybdenum Co.

High Velocity Extrusion of Tungsten and Molybdenum:
W. Pollock and *C. D. Dickinson*, General Telephone and Electronics Corp.

Fabrication of Tungsten Shapes by Plasma Arc Spray Techniques:
R. H. Singleton, E. L. Bolin, and *F. W. Carl*, General Motors Corp.

Effect of Melting Variables on the Purity and Properties of Tungsten:
R. W. Campbell and *C. D. Dickinson*, General Telephone and Electronics Corp.

Extrusion Development of Columbium, Tungsten and Tantalum Alloys:
A. S. Nemy, Thompson Ramo Wooldridge Inc.

High Energy Rate Extrusion of Columbium-base Alloys:
R. T. Begley and *R. L. Ammon*, Westinghouse Electric Corp.

Processing and Properties of Columbium-base Alloy Cb-74:
C. R. McKinsey, A. L. Mincher, W. F. Sheely, and *M. Schussler*, Haynes Stellite Co.

Welding of Columbium and Its Alloys:
E. A. Franco-Ferreira and *G. M. Slaughter*, Oak Ridge National Laboratory

Graphite and Refractory Compounds

(Simultaneous Session)

2:00 pm — Embassy Room

Chairmen:
J. R. Tinklepaugh, Alfred University
W. A. Lambertson, Carborundum Co.

Bold type indicates summary paper.
Roman type indicates research results.

Thursday PM, April 27 Continued

Status and Future of Graphite and Refractory Compounds:
R. T. Doloff and *J. T. Meers*, National Carbon Co.

Tensile Properties of Pyrolytic Graphite to 5000°F:
W. V. Kotlensky and *H. E. Martens*, California Institute of Technology

High Temperature Deformation of Pyrographite:
J. Pappis, L. Hagen, N. Viola, and *S. Cvikevich*, Raytheon Co.

Mechanisms of Deformation and Fracture in Pyrolytic Graphite:
E. R. Stover, General Electric Co.

High Temperature Properties of Titanium Diboride:
V. Mandorf, J. Hartwig, and *E. J. Seldin*, National Carbon Co.

Refractory Beryllium Compounds:
W. W. Beaver and *A. J. Stonehouse*, Brush Beryllium Co.

Preliminary Investigation of Fabrication and Properties of Hafnium Carbide:
W. A. Sanders, J. W. Creagh, C. F. Zalabak, and *J. J. Gangler*, Lewis Research Center, NASA

Coatings on Refractory Metals

(Simultaneous Session)

2:00 pm — Lorenzo Carter Room

Chairman:
L. M. Raring, Pratt & Whitney Aircraft
D. Cona, Boeing Airplane Co.

Status and Future of High Temperature Coatings for Refractory Metals:
J. J. Gangler, Lewis Research Center, NASA

Coatings for Molybdenum:
R. L. Wachtel, Chromalloy Corp.

Mechanisms of Formation and Protection of Columbium-Zinc Coatings on Columbium:
G. Sandoz and *T. C. Lufton*, Naval Research Laboratory

Protection of Columbium Alloys for High Temperature Service:
E. N. Bamburger, R. G. Frank, L. Luft, and *E. D. Sayre*, General Electric Co.

Ceramic Coatings for the Protection of Columbium Alloys:
W. B. Hall and *J. W. Graham*, General Electric Co.

High Temperature Oxidation Resistant Coatings for Columbium Alloys:
R. A. Jeffries and *J. D. Gadd*, Thompson Ramo Wooldridge Inc.

Aluminide and Beryllide Protective Coatings for Tantalum:
D. D. Lawthers and *L. Sama*, Sylvania-Corning Nuclear Corp.

Bold type indicates summary paper.
Roman type indicates research results.

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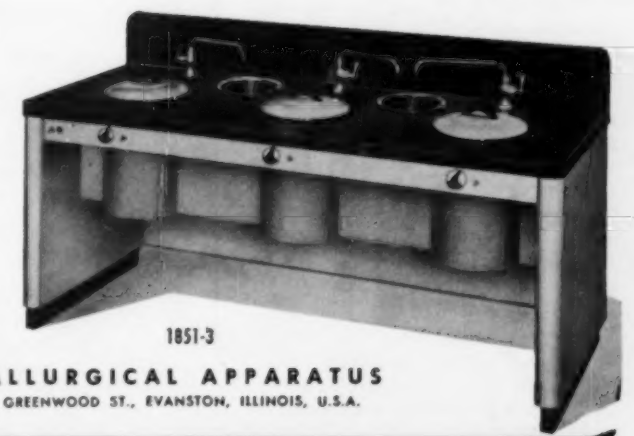

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STUDENT NEWS

ECPD State Committees Encourage Students To Study Engineering

The first step toward increasing the engineering population to meet future needs is to attract additional qualified high school students to the study of engineering, according to the Engineers Council for Professional Development (ECPD). This objective is being carried out by ECPD's Guidance Committee through a network of state committees which work directly with the schools.

Each year, thousands of engineers from the ECPD State Committees visit high schools across the country to tell the students about engineering and the aptitudes and preparation required for a career in this field.

The ECPD State Committees were organized during the Korean War when the shortage of engineers was reaching critical proportions. There are now committees in all 50 states, the District of Columbia, and Canada. The work is coordinated by the ECPD National Guidance Committee through eight Regional Chairmen.

The ECPD State Committees arouse interest in engineering through a variety of programs which include talks and panel presentations, the showing of films on engineering, inspection trips, promotion of high school engineering clubs and science fairs, television and radio programs, individual counseling, and many other activities. The ECPD National Guidance Committee supports the work of the State Committees through two annual mailings to the nation's 30,000 high schools.

The eight Regional Chairmen are: R. H. Stockard, University of Rhode Island, Kingston, R. I.; H. F. Roemmele, Copper Union, New York, N. Y.; D. M. Seeley, U. S. Steel Corp., Pittsburgh, Pa.; John C. Reed, University of Florida, Gainesville, Fla.; and G. P. O'Connell, General Motors Corp., Detroit, Mich.

Also, A. B. Drought, Marquette University, Milwaukee, Wis.; Robert Matteson, California Research Corp., Richmond, Cal.; and J. G. McGuire, Texas A. & M. College, College Station, Tex.

Battelle Memorial Institute

On December 7, Battelle was host to a group of students of local high schools who were invited by the Women's Auxiliary of AIME. The students were addressed by J. Harry Jackson, manager of the Metallurgy Dept., and by various officers and members of AIME. After lunch and a tour of more than 12 of the facilities of the Institute, Dr. C. H. Lorig and Mr. H. O. McIntire answered questions. The WAIME hostesses for the occasion were Mrs. J. H. Jackson, Mrs. A. R. Elsea, Mrs. Mars Fontana, Mrs. E. E. Underwood, and Mrs. H. B. Goodwin.

Cornell University

The Cornell Metallurgical Society met October 9 for their traditional faculty-student picnic. This was the first fall meeting of the group, and provided a chance for students and faculty to meet on an informal basis.

On November 3, Professor M. S. Burton of the Metallurgical Engineering School addressed the second meeting of the group. He discussed the new Metallurgical Engineering Building which will soon be erected. With the completion of the building, to be called Bard Hall, the School of Metallurgical Engineering will be an independent school at Cornell.

NEW STUDENT MEMBERS

Argonne National Laboratory
Aldred, Anthony T.

Polytechnic Institute of Brooklyn
Bonacorsa, Leonard M.

Carnegie Institute of Technology
Carr, William N.
Choi, Jei Y.
Ebihara, William T.

Colorado School of Mines
Dumm, Roger H.
Johnson, Tim C.

Columbia University
Guberman, Herbert D.

University of Delaware
Currier, Thomas E.

University of Idaho
Carney, Thomas R.
Richardson, Jimmie L.

Iowa State University
Miller, Albert E.

Mackay School of Mines
Flynn, Patrick T.

Massachusetts Institute of Technology
Shaimoto, Shigeo

University of Michigan
Merriman, Edmund A.

University of Minnesota
Lu, Wei Hao

Missouri School of Mines
Benn, Edward
Brown, Robert S.
Clark, Clinton A.
Dagley, Richard K.
Delling, David R.
Dix, Larry L.
Dreyer, Dennis G.
Gerhardt, Paul C.
Grechus, Garland K.
Hellman, Ronald E.
Lampe, Thomas B.
Ogle, James R.
Roberson, Charles M.
Silbey, Val
Stigall, Garry E.

Montana School of Mines
Ekstrom, Darwin D.
Kowtow, Raymond
Trask, Frank, III
Young, Joseph L.

New Mexico Institute of Min. & Tech.
Brooke, James N.

Northwestern University
Adsit, Norman R.

University of Oregon
Meck, Robert A.

University of Pennsylvania
Deitch, Richard
New, Charles E.

Pennsylvania State University
Stevens, Eriano P. Jr.

University of Pittsburgh
Joyce, John F.

Purdue University
Jordan, Albert G.
Tobin, Philip J.

Rensselaer Polytechnic Institute
Crowley, Edward J.
Enis, Allan
Krysiak, Kenneth F.
Sherman, Charles I.

Royal School of Mines (London)
Sastri, Alyaswami S.

South Dakota School of Mines
Johnson, Andrew M.
Maciejewski, Frank C.

Syracuse University
Kerner, Arthur A.
Sessler, John G.

Texas Western College
McDaniel, Roger L.

University of Washington
Ault, Earle A.
Clark, D. G.
Uchida, Jack M.
Von Krosiek, Sam R.

Washington State University
Baggerly, Roy G.

Wayne State University
Ulatowski, Leonard L.
Winquist, Lauren A.

MEMBERSHIP

Proposed for Membership
Metallurgical Society of AIME

Total AIME members on December 31, 1960, was 34,852; in addition 1,893 Student Members were enrolled.

ADMISSIONS COMMITTEE

W. L. Brytczuk, Chairman; S. C. Carapella, Jr.; J. W. Hanley; T. D. Jones; H. C. Larson; Harold Margolin; Shadburn Marshall.

The Institute desires to extend its privileges to every person to whom it can be of service, but does not desire as members persons who are unqualified. Institute members are urged to review this list as soon as possible and immediately to inform the Secretary's office if names of people are found who are known to be unqualified for AIME membership.

Members

Agrawal, Bal C., Madison, Wis.
Beachum, Edward P., Bethlehem, Pa.
Brown, John A., Trail, B. C., Canada
Davies, Emrys, Wrexham, North Wales, Great Britain
Dennis, Phil B., Welland, Ont., Canada
Farrell, Thomas B., Pittsburgh, Pa.
Freni, Elio R., San Gavino, Sardinia, Italy
Grojotheim, Kai, Trondheim, Norway
Hanson, Everett W., New York, N. Y.
Harada, Keiji, Kawasaki, Japan
Johnson, Robert N., Palo Alto, Calif.
King, Alwyn H., Cambridge, Mass.
Lash, Leslie D., Salt Lake City, Utah
Lowe, James R., Pittsburgh, Pa.
Rowland, Theodore J., Niagara Falls, N. Y.
Rudolf, William, New York, N. Y.
Schieflow, Odd, New York, N. Y.
Schubert, Carl D., Chicago, Ill.
Shimaoka, Goro, Tokyo, Japan
Southard, William D., Salt Lake City, Utah
Stryker, Robert S., Bethel Park, Pa.
Sudbury, Michael P., Falconbridge, Ont., Canada
Townley, Leigh M., Watervliet, N. Y.
Wadson, Gerald C., Detroit, Mich.
Weisman, Sidney, New York, N. Y.

Associate Members

Sachchidanandi, Sinha, Cleveland, Ohio

Junior Members

Dahlman, William H., Calumet City, Ill.
Deubler, Klaus, Fontana, Calif.
Edwards, Theodore, Schenectady, N. Y.
Eustice, Albert L., Wilmington, Del.
Feige, Norman G., New York, N. Y.
Merchant, Harish D., Toledo, Ohio
Myles, Kevin M., Argonne, Ill.
Nesslage, Konald J., Elizabeth, N. J.
Peto, Jean C., Paris, France
Ragan, Albert J., McKeesport, Pa.
Swear, William T., East Helena, Mont.
Szymczak, Matthew, Oaklawn, Ill.

REINSTATEMENT—MEMBER

Kimzey, W. Dwight, Columbia Falls, Mont.
Li, Sing Bay, Ridgewood, N. J.
Yamamoto, Joe S., Gardena, Calif.

REINSTATEMENT—CHANGE OF STATUS

Junior to Member

O'Laughlin, George W., Canton, Ohio

Student to Member

Whitney, Loren L., Cleveland, Ohio

Associate to Member

Bauer, Richard J., Brooklyn, N. Y.
Bishop, Harry L., Jr., Brackenridge, Pa.
Dickey, William H., Brackenridge, Pa.
Fincham, Christopher J., Boston, Mass.
Gross, Jason, Northridge, Calif.
Guard, Ray W., Berkeley, Mich.
Haasen, Peter, Gottingen, Germany
Hagel, William C., Schenectady, N. Y.
Hayes, Daniel J., Dearborn, Mich.
Heiniemann, Frederick E., Albany, N. Y.
John, Glen O., Bristol, England
Kiessel, William R., Allen Park, Mich.
MacDonald, Robert J., Cleveland, Ohio
Ong, John N., Jr., St. Louis, Mo.
Parr, James G., Edmonton, Alta., Canada
Preston, Thomas B., Fonthill, Ont., Canada
Strasser, Alfred A., White Plains, N. Y.
Ziemann, John G., Utica, N. Y.

NECROLOGY

Year Elected	Name	Date of Death
1912	Elkan, Benno	Jan. 6, 1961
1936	Fitzgerald, Paul E.	Jan. 7, 1961
1948	Illidge, R. E.	Dec. 20, 1960
1902	Jameson, A. H. (Legion of Honor)	Unknown
1915	Johnson, F. A.	Unknown
1903	Miller, Emory T. (Legion of Honor)	Unknown
1930	Navrocky, Edw. R.	Dec. 5, 1960
1920	Peabody, H. W.	Dec. 28, 1960
1923	Shaw, Quincy A., Jr.	Unknown
1917	Smith, C. T.	Dec. 18, 1960
1921	Stauffer, C. R.	Unknown
1942	Treadwell, Harry A.	Dec. 17, 1960
1910	Tyssowski, John (Legion of Honor)	Nov. 24, 1960
1916	Walter, A. R.	Oct. 13, 1960

Landis Is Named New EJC President

James N. Landis, vice president of the Betchel Corp., of San Francisco, was elected president of the Engineers Joint Council (EJC) at a recent meeting of the council's board of directors. The board re-elected George E. Holbrook, vice president of E. I. du Pont de Nemours & Co., as vice president of EJC, a post which he has held during 1960.

Mr. Landis, a past president and present council member of ASME, succeeds Augustus B. Kinzel, vice president of Union Carbide Corp., who headed EJC last year. Mr. Landis received a BS Degree in Mechanical Engineering from the University of Michigan in 1922. He was with the Brooklyn Edison Co., from 1923 until 1936 when he joined Consolidated Edison where he remained until 1948. He joined Betchel that year as chief power engineer in charge of engineering design and layout of steam-power plants, becoming vice president in 1953. He lives in San Mateo, Calif., with his wife and five children.

Mr. Holbrook is also a University of Michigan graduate, having received a BS, MS, and Ph.D. (1933) in chemical engineering. He joined du Pont in 1933.

Herty Award

(*Continued from page 227*)

Herty by the publication of a memorial volume entitled *Deoxidation of Steel* in 1957. This book contains the most significant papers of Mr. Herty on the physical chemistry of steelmaking, many of which had originally been published as bulletins of the US Bureau of Mines, and are now difficult to obtain. Copies of *Deoxidation of Steel* ($7.00 to AIME members, $10.00 to non-members) may be purchased through the Book Order Dept., AIME, 29 West 39th Street, New York 18, N. Y.

Books

(*Continued from page 176*)

called *deactivators* and Type IIIA *passivators*.

The authors believe that the primary process in the action of many effective inhibitors is the formation, on the metal surface, of protective films composed of reaction products between the metal, the inhibitor, and the ions of the corrosive medium. All electrochemical processes—cathodic and anodic polarization, changes in hydrogen overvoltage, resistance at the metal-electrolyte boundary, etc.—are secondary processes dependent on the film-forming reaction. They state that electrochemical measurements are of use in studying inhibitors, but it is impossible to determine the chemical nature of the inhibitive process by these measurements alone.

Studies of mixtures of inhibitors are discussed and examples of synergism (one helps the other) and antagonism (two together worse than one) are given. Good discussions on dangerous inhibitors, chemisorption, effect of temperature, and effect of velocity of flow are presented. •

ASM Review of Metal Literature, 1959, edited by Marjorie R. Hyslop, American Society for Metals, 1266 pp., $25.00, 1960—The 16th annual collation of the monthly annotated survey of articles, technical papers, and reports dealing with the technology of metals, appearing in engineering, scientific, and industrial journals and books here and abroad. prepared at the Center for Documentation and Communications Research, Western Reserve University, Cleveland. •

Personals

(*Continued from page 184*)

eral superintendent of the Loraine (Ohio) works of National Tube.

C. H. Toensing has been appointed director, powder metals research, of Firth Sterling Inc. He was formerly manager of powder metals research.

Emmet A. Torney is now sales manager, primary metals, National Lead Co. He was formerly with Bunker Hill Co.

James S. Vanick, research metallurgist with the Development and Research div. of International Nickel Co., Inc., has retired after 38 years with the company. Mr. Vanick will serve on the staff of Modern Castings magazine as a contributing editor.

C. M. White, retired former chairman of Republic Steel Corp. has resigned as a member of the board of directors, as a member of the executive committee, and also as president of the American Iron & Steel Institute.

Coming Events

Mar. 8, 1961, Chicago Section, NOHC, Annual All-Day Meeting, Del Prado Hotel, Chicago, Ill.

Mar. 13-14, 1961, 59th Annual Meeting, Steel Founders' Society of America, Drake Hotel, Chicago.

Mar. 15, 1961, Cleveland Section, NOHC, Suppliers' Night, Pesano's, Garfield Heights, Ohio.

Mar. 20-22, 1961, Canadian Institute of Mining and Metallurgy, Annual General Meeting, Quebec City, Que., Canada.

Mar. 20-24, 1961, Western Metal Exposition & Congress, Pan Pacific Auditorium, Los Angeles.

Mar. 23, 1961, Northern Ohio Section, NOHC, Annual Off-the-Record Meeting, Pick-Ohio Hotel, Youngstown, Ohio.

Mar. 23-24, 1961, Third Annual Symposium on Electron Beam Technology, Boston.

Apr. 10-12, 1961, 44th National Open Hearth Steel Conference and Blast Furnace, Coke Oven, and Raw Materials Conference, Sheraton Hotel, Philadelphia.

Apr. 10-15, 1961, First International Congress on Metallic Corrosion, Imperial College of Science & Technology, London, England.

Apr. 12-14, 1961, AIME International Symposium on Agglomeration, Sheraton Hotel, Philadelphia.

Apr. 13-15, 1961, Pacific Northwest Metals & Minerals Conference, Spokane, Wash.

Apr. 24-25, 1961, AIME Southwest Minerals Industry Conference, Stardust Hotel, Las Vegas, Nev.

Apr. 26-27, 1961, Cleveland Section and The Metallurgical Society, Technical Conference on High Temperature Materials, Hotel Carter, Cleveland.

May 17, 1961, Joint Meeting of Powder Metallurgy Group and Physical Metallurgy Group of the New York Section, Brass Rail Restaurant, New York.

May 17-19, 1961, The Metallurgical Society, Management of Materials Research Conference, Arden House, Harriman, N. Y.

May 18-19, 1961, AIME 15th New England Regional Conference, Hotel Van Curler, Schenectady, N. Y.

Aug. 30-Sept. 1, 1961, AIME Third Technical Conference on Semiconductors, Ambassador Hotel, Los Angeles.

Oct. 17-Nov. 7, 1961, Visit of the Iron & Steel Institute (United Kingdom) to the United States.

Oct. 23-26, 1961, Fall Meeting of The Metallurgical Society of AIME, Pick-Fort Shelby Hotel, Detroit.

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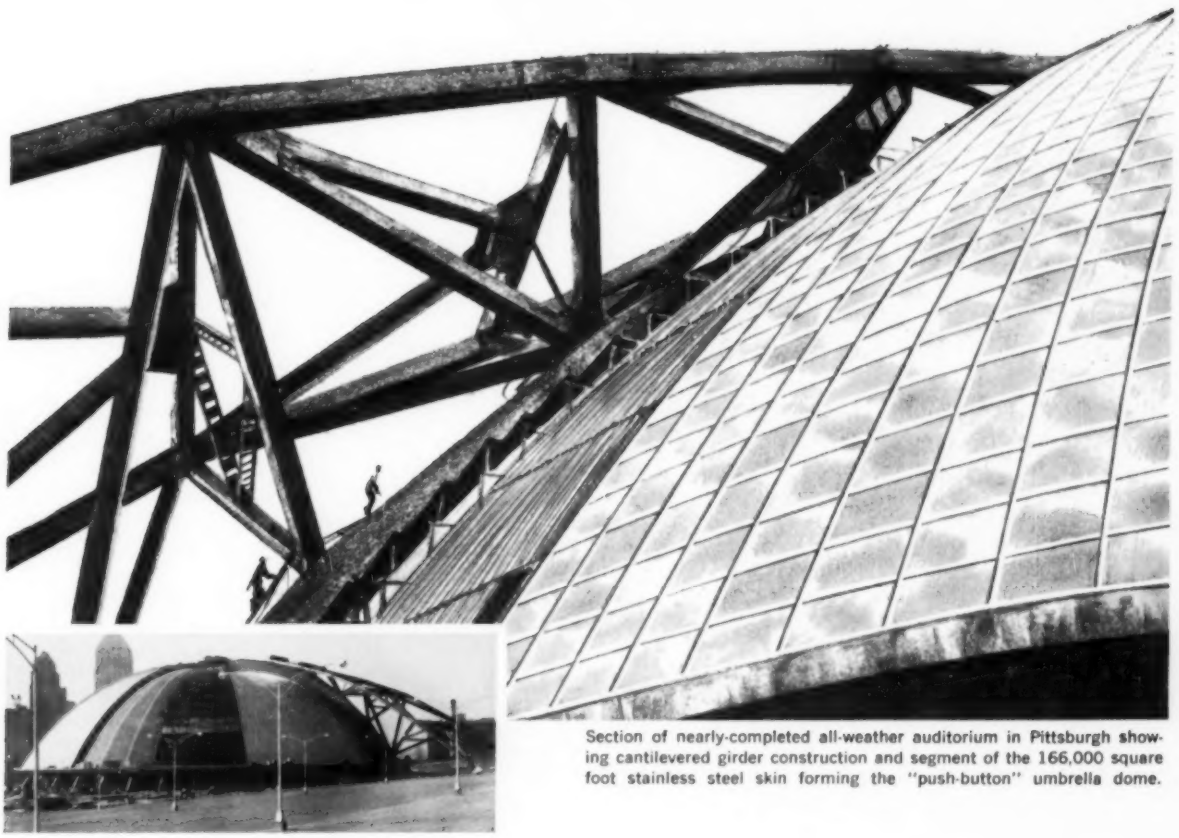

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